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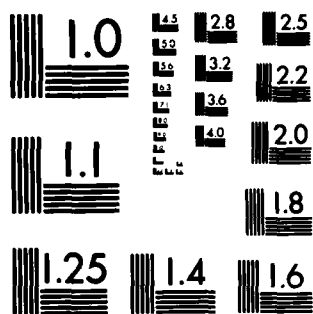
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Contract No. N00039-84-C-0070

IITRI

COMPILATION OF 1985 ANNUAL REPORTS  
OF THE NAVY ELF COMMUNICATIONS SYSTEM  
ECOLOGICAL MONITORING PROGRAM

Volume 1 of 3 Volumes: TABS A-C

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July 1986

Prepared for:

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Communications Systems Project Office  
Washington, D.C. 20363

Prepared by:

IIT Research Institute  
10 West 35th Street  
Chicago, Illinois 60616

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to Electromagnetic Fields,  
University of Wisconsin-Parkside  
Goodman, E.M.; Greenebaum, B.

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## FOREWORD

This document is the fourth compilation of Annual Reports on the Extremely Low Frequency (ELF) Communications System Ecological Monitoring Program initially authorized under Naval Electronic Systems Command Contract N00039-81-C-0357 to IIT Research Institute (IITRI). The studies in this Program are now being continued under Space and Naval Warfare Systems Command Contract N00039-84-C-0070. IITRI provides engineering support and coordinates the efforts of investigators in 10 studies, all of which are being conducted under subcontract arrangements between IITRI and the study teams.

The purpose of the Ecological Monitoring Program is to determine whether electromagnetic fields produced by the Navy's ELF Communications System will affect resident biota or their ecological relationships. Biological aspects of 16 general types of organisms and ecological aspects of three ecosystems are being monitored in Wisconsin and Michigan.

The originally proposed study objectives, monitoring protocols, and analytical techniques were presented in the 1982 compilation of annual reports. Changes and study progress are documented in subsequent compilations. Commencing in 1983, each annual report has been reviewed by four scientific peers. Two of the four are selected by the reporting investigator; the other two are selected by IITRI. Critiques are supplied to the authors for their consideration in finalizing their annual reports and in planning the next field season.

Each compilation was printed from original copies of each investigator's report for 1985 without change or editing by either IITRI or the Space and Naval Warfare Systems Command.



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ELF ECOLOGICAL MONITORING PROGRAM  
INDEX OF 1985 ANNUAL REPORTS

- A. Herbaceous Plant Cover and Tree Studies  
Michigan Technological University  
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to Electromagnetic Fields  
University of Wisconsin-Parkside  
Goodman, E.M.; Greenebaum, B.
- D. Soil Amoeba  
Michigan State University  
Band, R.N.
- E. Soil and Litter Arthropoda and Earthworm Studies  
Michigan State University  
Snider, R.J.; Snider, R.M.
- F. Biological Studies on Pollinating Insects: Megachilid Bees  
Michigan State University  
Fischer, R.L.
- G. Small Vertebrates: Small Mammals and Nesting Birds  
Michigan State University  
Beaver, D.L.; Asher, J.H.; Hill, R.W.
- H. Aquatic Ecosystems  
Michigan State University  
Burton, T.M.; Stout, R.J.; Taylor, W.W.; Muzzall, P.M. Oemke, M.P.;  
Glosser, R.; O'Malley, M.; Whelan, G.
- I. Wetland Studies  
University of Wisconsin-Milwaukee  
Stearns, F.; Guntenspergen, G.; Keough, J.; Wikum, D.
- J. Bird Species and Communities  
University of Minnesota-Duluth  
Niemi, G.J.; Hanowski, J.M.

ELF COMMUNICATIONS SYSTEM ECOLOGICAL MONITORING PROGRAM:  
HERBACEOUS PLANT COVER AND TREE STUDIES


The Michigan Study Site

Tasks 5.13/5.14

ANNUAL REPORT 1985

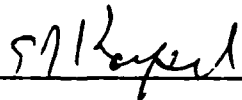
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PROJECT COORDINATOR:

  
Glenn D. Mroz  
Assistant Professor

INVESTIGATORS: Charles Becker  
Johann Bruhn  
Peter Cattelino  
Leslie Fuller  
Martin Jurgensen  
Kathleen Lederle  
Hal Liechty  
Glenn Mroz  
David Reed  
Elizabeth Jones Reed  
Dana Richter  
Carl Trettin

RELEASING AUTHORITY:



MICHIGAN TECHNOLOGICAL UNIVERSITY  
HOUGHTON, MICHIGAN

## TABLE OF CONTENTS

	<u>Page</u>
Introduction.....	1
Element 1: Plot Selection.....	7
Element 2: Development, Installation and Operation of the Ambient Monitoring System.....	15
Element 3: Tree Productivity.....	69
Element 4: Phenophase Description and Documentation.....	114
Element 5: Herbaceous Vegetation Cover and Growth.....	144
Element 6: Mycorrhizal Fungi Collection.....	151
Element 7: Mycorrhiza Characterization and Root Growth.....	162
Element 8: Litter Production.....	172
LITERATURE CITED.....	181
APPENDIX A: Profile Descriptions of the Soil Occurring on the Ground, Antenna, and Antenna Sites.....	185
APPENDIX B: Ambient Sensor Configuration , Sampling Peroids, and Ambient Summary Tables.....	207
APPENDIX D: Average Incremental Diameter Growth by Week for Each Species and Each Diameter Class.....	215
APPENDIX E: Diameter Growth Models Used in Comparison Analysis to Observed Diameter Growth.....	225
APPENDIX F: Performance of Existing Diameter Growth Models in Predicting Diameter Growth on ELF Study Sites.....	231
APPENDIX G: Maps of the Three Study Sites of the Trees and Herbaceous Plants Study.....	235
APPENDIX H: Average Values for Seedling Measurement by Site and Date for 1985 Growing Season.....	239

## INTRODUCTION

The broad objectives of this study remain: 1) to investigate and characterize the growth of trees and herbaceous plants on selected plots within the ELF antenna area prior to the operation of the antenna, and 2) to use this baseline data to evaluate the possible effects of ELF electromagnetic fields on growth after the antenna begins operation.

The general approach of the study requires study plots to be located along a portion of the antenna, at a ground site and at a control site located some distance from the antenna. While a major effort of the early years of this study centered on locating plots within very similar ecosystems, some variation among and within sites is inevitable. Thus, it is of great importance in this study which is evaluating what may be very subtle ELF effects, to have a statistically rigorous design. It is also imperative to directly measure plant growth as well as soil and site factors which are important regulators of the growth process.

In a departure from past years' reports, we thought it best to begin this report with a discussion of how data, both before and after an operation of the antenna as well as between sites from one year to the next will be analyzed. A discussion of the covariate analysis is included. Hypotheses of specific study elements are listed in later discussions as are modifications from the general design. One other noteworthy change is that Element 9 - Data Management has been deleted from this years report since the management of data is evident throughout the discussion of individual elements.

## Experimental Design

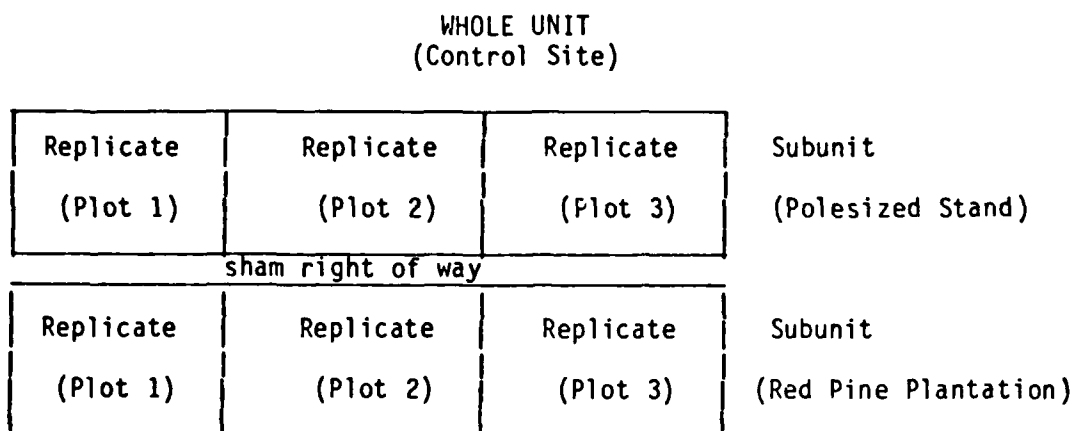
### Split Plot in Space and Time

The experimental design for the ELF environmental monitoring program may be described as a split plot in space and time. A split plot design deals with a single level of one treatment which is applied to a relatively large area (referred to as the whole plot). Levels of a second treatment are applied to distinct subplots within the whole plot. The split plot design has two treatment factors and experimental units: whole plots and subplots. Time becomes an important variable in the analysis since data are analyzed from year to year without rerandomization of treatments. This involves successive observations made on the same whole unit over a period of time. A combined analysis can be made to determine the average treatment response (site difference) over all years and whether they are consistent from year to year (Steel and Torrie 1980).

Three sites have been chosen from which measurements are taken: the ground, the antenna, and the control sites. These are considered the whole plots in the design. The treatment factor for this level of the design is the degree of exposure to ELF after the antenna has become operational. Each site (whole plot) is subdivided into two stand types (subplots). Polesized trees and red pine plantations comprise the treatment factor for the second level of the design. Each stand type is replicated three times to control variation on a site across the treatments. The time factor is the number of years in which the experiment is conducted or the number of sampling periods in one season. Figure 1 shows the configuration of one site (the control) and how it relates to the experimental design. Each site follows the outline with one exception. The ground site has only the red pine plantation, thus eliminating one treatment factor.



Figure 1. Diagram of the control plot as an example of the experimental design units.



Depending on the variable of interest the stand type treatment factor may or may not be pertinent. In those cases where measurements are made on only one stand type, the stand type treatment factor becomes irrelevant and falls out of the analysis; all else remains unchanged. This would be true for analyses such as diameter growth on polesized trees (Element 3). Measurements are made only in the polesized stands, so no differentiation of stand type (plantation versus polesize) exists.

#### Analysis of Covariance

There are two general methods for controlling variability due to experimental error. Direct control to increase precision in the study is achieved in the experimental design, which in our case is the split plot in space and time. Indirect or statistical control to increase precision and to remove potential sources of bias may be achieved through the use of covariate analysis. This involves the use of variables (covariates) which are related the variable of interest (variate) to adjust the measurements of the variate. The function of covariance can be the same as that of local control (pairing and blocking) in that it removes the effects of an environmental source of variation that would otherwise inflate the

experimental error. The covariate need not be a direct causal agent of the variate, but merely reflect some characteristic of the environment which also influences the variate (Cochran, 1957). Assumptions necessary for valid use of analysis of covariance are:

- 1) the covariates are fixed, measured without error, and independent of treatments
- 2) after removal of treatment differences, the response of the variate from the covariates is linear and independent
- 3) the residuals are normally and independently distributed with mean zero and equal variance

If more than one covariate is included in the analysis, the assumptions remain the same for each covariate, though they do not apply among the covariates themselves (Cochran and Cox, 1957).

While covariates are used in an analysis to reduce experimental error, they should also be unaffected by the different treatment factors (site and stand type as well as ELF). When the covariate is actually affected by the treatment, the adjustment process removes more than what can be considered an error component from the variate. It may also remove or distort part of the treatment affect on the variable of interest. Determining the proper covariates (both biologically meaningful as well as independent of treatment effects) will be one of the most important processes of the analysis. An F-test of treatments against error for the covariate can be helpful when there is doubt whether treatments have some effect on the covariate (Smith, 1957).

The assumption that the relationship between the covariate(s) and the variate be linear is less restrictive than it first appears (Lindman, 1974). Transformation of the covariate may achieve the linearity required. For example, the relationship between the variate and the square of the covariate or the natural logarithm of the covariate may be linear.

Secondly, the relationship of the variate with that of the covariates may or may not be linear, but a linear relationship is often a reasonably good approximation for a nonlinear relationship provided that the range in values of the covariates are not too large (Cochran, 1980). Plots of variate(s) versus covariate(s) with all other factors held constant, are being made to examine each relationship.

Transformation of the covariates may also be useful in stabilizing variances if the third assumption of equal variances is violated. Evidence from the usual analysis of variance indicates that F-tests in the analysis of covariance are robust with respect to the violation of the assumption of normality and homogeneity of the residual variance (Winer, 1971).

Thus, violation of the assumptions of independence from treatment effects and linearity with the variate are the more important considerations. The degree of robustness with respect to these two assumptions is unknown for the analysis of covariance. If covariates violate these assumptions, then alternative covariates will need to be considered.

In summary, the overall experimental design is a split plot in space and time combined with the analysis of covariance. This will allow for the control of variability due to experimental error both through direct control as well as statistical methods, and thus increase precision in the experiment. The most general and encompassing ANOVA table for the project is shown in Table 1. ANOVA tables for each specific experiment are displayed and discussed in the respective elements.

Table 1. Generalized analysis of variance table for the trees and herbaceous plant cover study.

Source of Variation Covariates	Degrees of Freedom # Covariates	Sum of Squares	Mean Square	F-Ratio
Plot	2	$SS_P$	$MS_P$	$MS_P/MS_{E(S)}$
Site	2	$SS_S$	$MS_S$	$MS_S/MS_{E(S)}$
Error (S)	4-# Covariates	$SS_{E(S)}$	$MS_{E(S)}$	
Stand Type	1	$SS_T$	$MS_T$	$MS_T/MS_{E(ST)}$
Site x Stand Type	2	$SS_{ST}$	$MS_{ST}$	$MS_{ST}/MS_{E(ST)}$
Error (ST)	6	$SS_{E(ST)}$	$MS_{E(ST)}$	
Years	#yrs-1	$SS_Y$	$MS_Y$	$MS_Y/MS_{E(SY)}$
Site x Years	(2)(#yrs-1)	$SS_{SY}$	$MS_{SY}$	$MS_{SY}/MS_{E(SY)}$
Error (SY)	(2)(2)(#yrs-1)	$SS_{E(SY)}$	$MS_{E(SY)}$	
Stand Type x Year	(1)(# yrs-1)	$SS_{TY}$	$MS_{TY}$	$MS_{TY}/MS_{E(TY)}$
Site x Stand Type x Year	(2)(1)(# yrs-1)	$SS_{STY}$	$MS_{STY}$	$MS_{STY}/MS_{E(STY)}$
Error (STY)	(2)(3)(1)(# yrs-1)	$SS_{E(STY)}$	$MS_{E(STY)}$	

## ELEMENT 1. PLOT SELECTION

Detection of possible ELF electromagnetic field effects on forest ecosystems requires the careful matching of plots to reduce variability among sites. Therefore, environmental factors that influence vegetation have been considered in selecting study sites. The study design for investigating possible ELF effects on trees and herbaceous plants required plots to be located along the antenna, at the antenna ground, and at a control site located some distance from the antenna. Soil characteristics, microclimate, site history, and the vegetative community were carefully evaluated to ensure as much similarity between test and control plots as possible. Field measurements used for determining similarity among sites are shown in Table 1.1.

Last year's report focused on comparisons of stand and site factors among the three sites. Site factors, stand composition, and herbaceous species composition were found to be similar enough among sites to meet study requirements. In addition, stand age and site productivity (as measured by site index) were similar, but measures of standing crop biomass were more variable due to lower stocking levels at the antenna site. Data analyses have been modified this year to account for ELF site variability over the large geographic antenna area. (see Experimental Design - Introduction). While soils at the sites are similar enough to support similar vegetative communities, some variation in soil properties exist among the sites. The following will summarize the soil characterizations on each site and discuss future directions in soil monitoring.

Table 1.1. Criteria used for selecting ELF study sites.

<u>Trees</u>	<u>Ground Flora</u>
*Species composition	*Species composition
*Basal area	*Frequency
*Diameter distribution	*Crown coverage
*Site index	
<u>Soil Morphology</u>	<u>Site</u>
*Horizon identification	*Slope
*Horizon thickness	*Aspect
*Texture	*Landform
*Drainage	*Habitat type
*Presence or absence of earthworms	
*Rock abundance	

### Sampling and Data Collection

Reconnaissance investigations of each study area were conducted by making auger borings to 1.5 meters and describing horizon properties to assess the uniformity of soil conditions. A soil pit was excavated at a representative location adjacent to the study plots and a detailed profile description made according to the National Cooperative Soil Survey Standards. Bulk density samples and soil samples for physical and chemical analyses were obtained from each soil horizon. To quantify soil chemical variability within the rooting zone, composite samples were obtained from the upper 4 mineral soil horizons by extracting five individual cores from a 2 m<sup>2</sup> area at each plot. Two sets of composites were sampled from each

plot. All samples were returned to the Soil Research Laboratory at Michigan Technological University for subsequent physical and chemical analyses using standard analytical techniques (Soil Conservation Service, 1972).

### Progress

### Soil Classification

The soils on the three study sites, although morphologically similar in surface horizons, are classified differently (Table 1.2). Field descriptions appear in Appendix A.

Table 1.2. Soil classification of the three ELF study sites.

<u>Site</u>	<u>Classification</u>
Ground	Typic Dystrocrept, sandy, mixed, frigid
Antenna	Entic Haplorthod, sandy, mixed, frigid
Control	Alfic Haplorthod, coarse-loamy, mixed, frigid

The control site exhibits the most soil development with the presence of well defined spodic and argillic horizons. The soil on the antenna site classified to the same great group level, but differs because of the amount of clay in the B horizon (Table 1.3). The soil at the ground site is also morphologically similar to the control, but is classified as an inceptisol because of the weak development of the spodic and argillic horizons.

### Soil Physical Properties

Soil horizon designations and depth are similar for the surface soil (approximately the top 50 cm) on all sites (Table 1.3). Surface soil horizons range from sands to loamy sands and thus exhibit relatively low water retention capacities. Bulk densities are moderate on all sites.

Subsurface horizons (generally greater than 50 cm depth) show greater variability in morphology as depicted by horizon designation. However, subsoils are similar in texture to surface horizons with only the E' horizon on the control site having a different designation (sandy loam) because of slightly greater clay content. Water retention for all subsoils are similarly low.

Rock fraction differences among soils on the site also appear to exist (Table 1.4).

**Table 1.4. Comparison of soil coarse fragments (>2mm) estimated by volume during pit description and by weight using large volume soil samples.**

<u>Site</u>	<u>Coarse Fragments</u>		<u>Std. Deviation for Weight Basis</u>
	<u>Volume Basis</u>	<u>Weight Basis</u>	
	-----%		
Ground	2-70	68	30.9
Antenna	0-30	13	11.1
Control	0-70	4	3.2

Initial estimates of rock content were made prior to plot establishment of a percent volume basis during soil characterization efforts. These percent volume estimates (Table 1.4) showed considerable variation among horizons. This is typical in glacial till soils with some horizons having no rocks and others ranging up to 70% rocks, especially in the C horizon. To further



TABLE 1.3. SOIL PHYSICAL PROPERTIES AT THE GROUND, ANTENNA AND CONTROL SITES.

HORIZON	DEPTH CM			BULK DENSITY g/cc			WATER RETENTION cm/cm		
	GROUND	ANTENNA	CONTROL	GROUND	ANTENNA	CONTROL	GROUND	ANTENNA	CONTROL
A	0-5	0-3	0-4	1.37					0.12
E	5-14	3-14	4-9	1.40	1.02	1.17	0.06	0.26	0.06
Bs1	14-45	14-28	9-32	1.31	1.31	1.26	0.05	0.02	0.04
Bs2	45-72	28-44	32-55	1.39	1.41	1.34	0.03	0.03	0.01
Bs3		44-67						0.01	
2Bt	72-92						0.04		
2BC		67-91			0.94				
E'			55-67			1.47			0.09
B/E			67-124						0.03
C			124+			1.56			0.01
2C	92+	91+			1.17			0.35	

HORIZON	CLAY %			SILT %			SAND %		
	GROUND	ANTENNA	CONTROL	GROUND	ANTENNA	CONTROL	GROUND	ANTENNA	CONTROL
A	3.7	4.1	5.3	13.9	17.7	25.9	82.4	78.2	68.8
E	2.3		2.3	10.7	12.2	23.1	87.0	87.0	74.6
Bs1	3.2	3.7	2.8	10.7	10.9	16.9	86.1	85.4	80.3
Bs2	2.7	0.5	2.7	5.4	5.1	6.9	91.9	94.4	90.4
Bs3					1.7			98.3	
2Bt	0.9			10.7			88.4		
2BC		1.0			0.5			89.7	
E'			6.0			26.5			67.5
B/E			5.5			13.0			81.5
C			2.3			2.2			95.5
2C	2.7	1.0		11.4	0.1		85.9	90.1	

investigate the effect of coarse fragments and possible relations to tree and herb growth, additional large volume soil samples were taken which could be converted to a more precise measure of coarsened fragments. This work, initiated in the fall, was interrupted by severe winter weather after only three samples were taken at each site. These showed high variability. More samples, stratified by depth, will be taken in spring 1986.

Available water and soil nutrients are reduced as soil volume is reduced by rock content. For example, soil nutrient values from the upper 50 cm of soil at the three study sites reflect the effect of rock content and are given in Table 1.5.

Table 1.5. Soil nutrients ( $\text{kg ha}^{-1}$  of the upper 50 cm) of the three study sites ( $n=25$ ).

	Ground	Antenna	Control
	-----Kg $\text{ha}^{-1}$ -----		
N	1533	3887	4170
K	117	236	390
Ca	786	1579	2573
Mg	111	224	321

#### Soil Chemical Properties

Soil chemical properties important for plant growth are presented in Table 1.6. Phosphorous data are not available at this time because an error was detected in a new technique being used. This problem has been corrected and soil phosphorus analysis are currently being performed

Soil pH was higher in surface soil horizons at the ground than at the control and antenna site, but subsoil horizons were quite similar. As expected, cation exchange capacity (CEC) is generally low as expected because of the sandy soil texture, but variable. Levels of calcium,

TABLE 1.6. SOIL CHEMICAL PROPERTIES AT THE GROUND, ANTENNA AND CONTROL SITES.

HORIZON	pH			CEC meq/100g			CALCIUM meq/100g		
	GROUND	ANTENNA	CONTROL	GROUND	ANTENNA	CONTROL	GROUND	ANTENNA	CONTROL
A	5.3	4.1	4.1	18.8	50.7	23.4	9.8	6.9	3.4
E	5.5	4.5	4.4	3.4	1.9	3.9	1.0	0.2	TR
Bs1	5.7	5.2	6.0	2.3	5.1	5.0	0.4	0.2	1.5
Bs2	6.3	5.7	6.2	1.3	1.7	2.9	0.3	0.1	1.1
Bs3		5.7			0.2			0.1	
2Bt	6.6			3.8			0.6		
2BC		4.0			0.8			0.3	
E'			6.0			5.3			3.1
B/E			5.9			4.5			2.2
C			6.2			2.2			0.7
2C	6.5	5.2			0.8			0.8	

HORIZON	MAGNESIUM meq/100g			POTASSIUM meq/100g			NITROGEN %		
	GROUND	ANTENNA	CONTROL	GROUND	ANTENNA	CONTROL	GROUND	ANTENNA	CONTROL
A	1.7	2.0	1.7	0.60	0.70	0.40	0.008	0.000	0.240
E	0.3	0.2	0.1	0.10	TR	TR	0.048	0.047	0.035
Bs1	0.1	0.2	0.4	0.10	TR	0.10	0.631	0.061	0.034
Bs2		0.1	0.7	TR	TR	0.10	0.959	0.049	0.017
Bs3		0.1			TR			0.097	
2Bt	0.2			0.10			0.002		
2BC		0.3			TR			0.049	
E'			1.3			0.10			0.013
B/E			1.2			0.10			0.005
C			0.9			TR			0.001
2C		0.4			TR		0.130	0.048	

magnesium, potassium, and nitrogen were more variable in surface horizons than the subsoil.

While soil nutrient, cation exchange capacity, and pH values for these soils are considered to be almost universally low by soil analyses standards, the variability among and within the study sites has been a cause for concern. Last year's report showed coefficients of variation for soil nutrients ranging from 10 to 100 percent, which is typical of glaciated soils. Since these soil properties, particularly soil nutrient availability may be used as covariates in growth response analyses, additional sampling is being done to refine this site variation. This effort, together with the slight modification of the experimental design described in the Introduction, will be used to distinguish ELF field effects among plots from the natural variability due to site differences.

## **ELEMENT 2. DEVELOPMENT, INSTALLATION AND OPERATION OF THE AMBIENT MONITORING SYSTEM.**

The growth and development of a forest community, or an individual in the community, is directly related to all the environmental factors (natural and man-induced) which influence the physical space the community or individual occupies. Any study which attempts to relate the development of a population to any one of these factors must also determine and screen out the effects of these other independent factors. Thus, variability in plant growth, development, or phenological events within the influence of the ELF antenna system must first be related to microclimatic variations before the effect of a single potentially subtle factor, such as the electromagnetic fields of the ELF antenna, (National Research Council, 1977), can be quantified.

Given the overall importance of microclimate to the Herbaceous Plant Cover and Tree Study Project, the objectives of the ambient monitoring element are to:

1. evaluate the natural climatic differences between the control study site and the sites within the influence of the ELF system.
2. evaluate the natural annual climatic changes of a site over time (thus, differences between pre-antenna and post-antenna operation).
3. develop an ambient data base which can be used to (1) build models to predict community growth and development as well as (2) supply ambient variables as covariates for community growth and development analysis, which are independent of ELF system effects.
4. evaluate the ELF system effects on nonindependent ambient variables.

Accomplishment of the first two objectives will not only document general

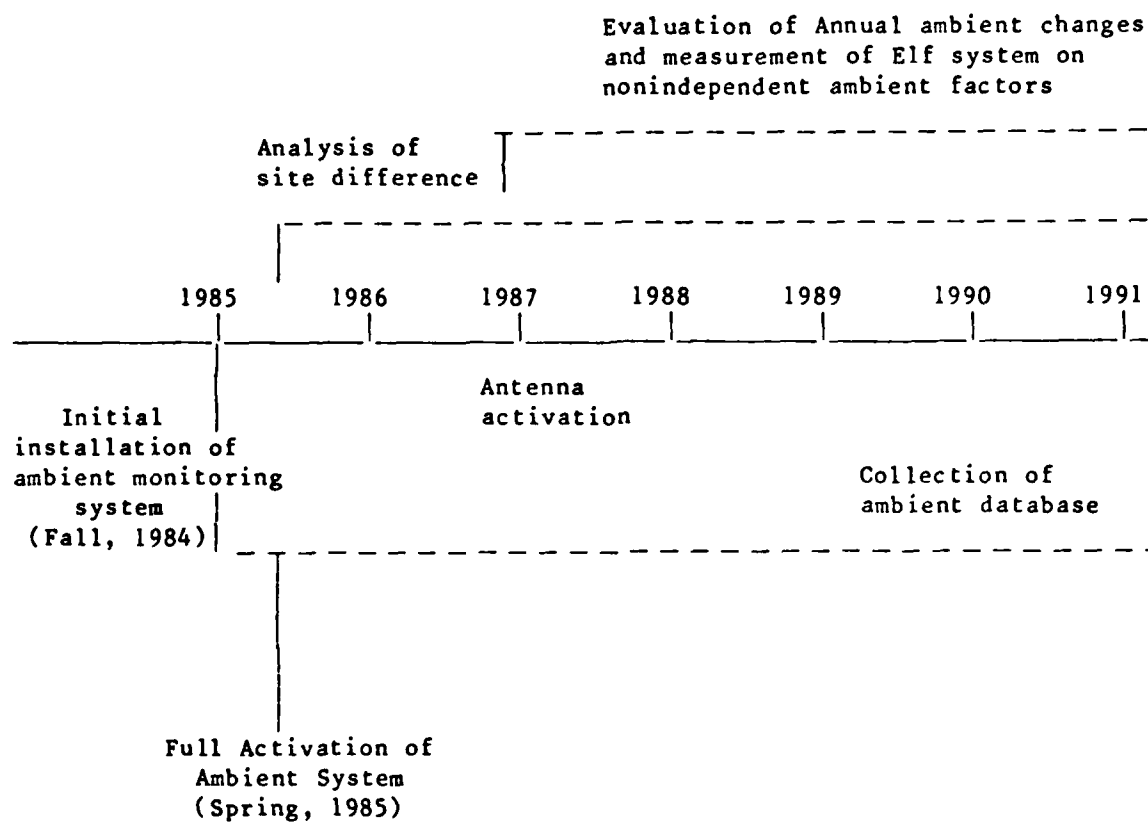
ambient differences among site and changes in annual climatic conditions, but also indicate ambient variables which will be potential candidates for growth and development modeling in various study elements. An adequate database of ambient measurements will insure a proper analysis of climatic relationships to other study components. The accomplishment of the last objective will give direct measurement (if any) of ELF system influences. The schedule and initiation of each phase of the objectives are presented in Figure 2.1. This year was the first full year of ambient data recording as well as the first year of site comparison.

### Sampling and Data Collection

#### System Configuration

The ambient variables measured in the study are air temperature (2 meters above the ground), soil temperature and soil moisture at depths of 5 and 10 cm, incoming global solar radiation (4 meters above the ground), relative humidity, photosynthetic active radiation (PAR) (30 cm above the ground), and air temperature (30 cm above the ground). The configuration and placement of the sensors on the study site are presented in Appendix B (Table 1). Because of the location of individual sensors, air temperature (2 meters above the ground), precipitation, relative humidity, and global solar radiation are independent of possible ecological changes caused by ELF electromagnetic fields. Soil temperature, soil moisture, air temperature (30 cm above the ground), and PAR (30 cm above the ground) may be more sensitive to ecological changes because these variables may be influenced by stand characteristics. The ecological relationships of each individual ambient factor to vegetation will be discussed later in the element.

Figure 2.1. Schedule and initiation of ambient monitoring objectives.



### System Maintenance and Performance

The end of 1985 concluded the first full year of the ambient system operation. As can be expected with any sophisticated system, some operational problems occurred and repairs to the system were needed (Figure 2.2). For example, the antenna site platform transmitter was returned to the manufacturer in the late winter and early spring for repair. Thus, ambient measurements for this site were not available until the first week in May.

The ground site platform also had problems with the internal clock which controls sampling times and transmission times. It was removed in June and returned to Handar for repairs. The same problem occurred again in August and the platform was returned. Total down time for the platform was approximately 5 weeks.

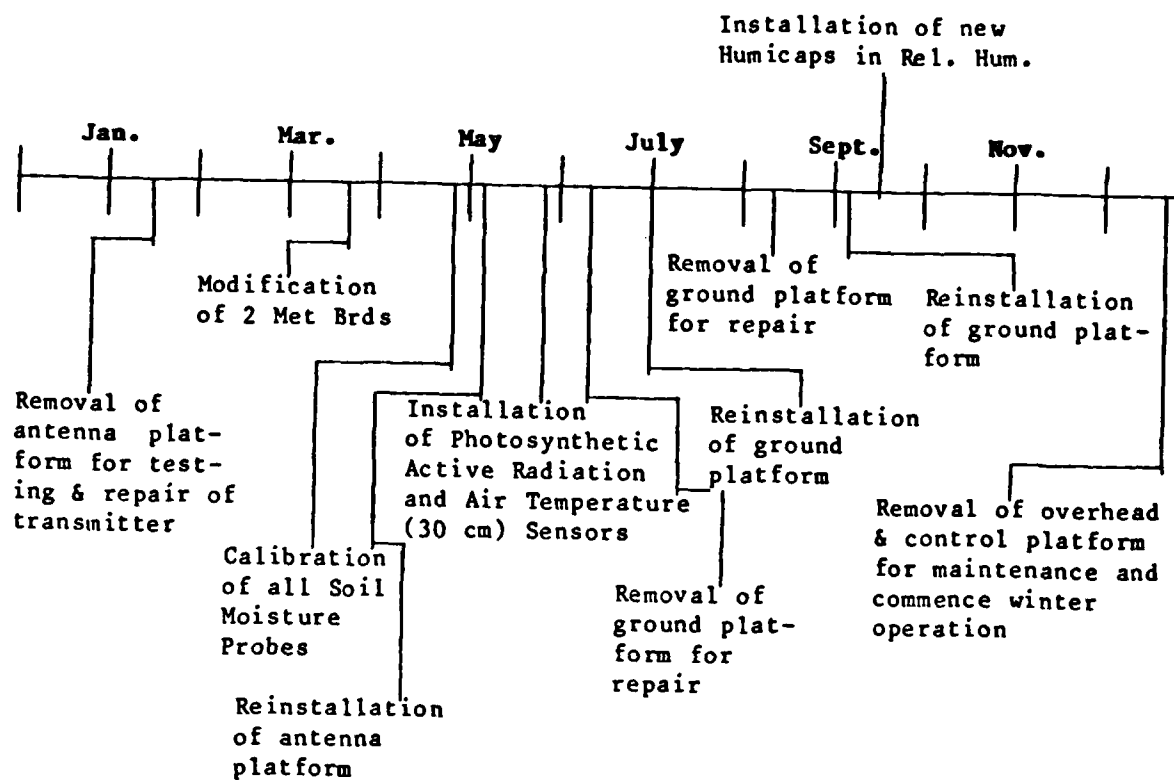
No further problems were experienced by the systems, however, in December the control and antenna site platforms were sent to the manufacturer for inspection. This should reduce future problems with these systems.

At the beginning of the year, the relative humidity sensors developed problems drifting from the calibration points. Attempts to recalibrate sensors failed. Replacement of the humicaps eliminated this problem in early July. Data prior to replacement were not reliable and could not be used.

In May, PAR and air temperature (30 cm above ground) sensors were received and installed. Some problems were experienced with the PAR sensors after heavy rainstorm events. Down time of these sensors was reduced by making the covers of calconnectors watertight.



Figure 2.2. Repair and downtime log.



### Data Management and Analytical Methods

The frequency, timing, and form of ambient measurements are presented in Appendix B (Table 1). Daily averages or totals, maximums, and minimums were computed for each sensor using all 3 hour measurements (eight per day) transmitted by the platforms. If less than six transmissions were received in a day for an air temperature, relative humidity, or solar radiation sensor, daily statistics for that sensor were not calculated. Due to small diurnal variability in soil temperature and soil moisture the transmission limits for calculation of daily statistics for these sensors were four and two transmissions respectively. Weekly averages or totals were then computed from these summaries.

Weekly summaries comprised the basic ambient unit used for site and time analysis for the 1985 growing season. The weekly ambient unit was adjusted to correspond to the weekly measurements of the tree productivity element. For example, if red pine height growth and pole-sized tree diameter growth were determined for the seven days from May 9 through May 15, weekly ambient summaries were also calculated for these same seven days. This insures a consistent relationship between ambient data and data recorded in the other elements. Weekly averages were considered missing and not calculated if less than four daily averages were computed from a sensor. Daily ambient information will be used for various elements such as the herbaceous study which has no set measurement period. Monthly averages and totals for various ambient factors were computed for the year as a whole. These summaries will be used for making annual comparisons beginning next year.

Comparisons of site differences of the ambient variables generally follow the split-plot in space and time experimental design described in the Introduction. However, due to variability of such ambient factors as

soil temperature or moisture in a plot and missing data from individual plots, the plot factor was removed from the experimental design for this element. Thus, the plots are treated as site replicates. The null hypothesis tested determines whether there are site differences for each individual ambient variable. If the stand type factor, site factor, or stand type-site interactions are significant, analysis was performed for each stand type separately. This gives a more sensitive analysis of site differences. If site-week interactions were significant, multiple range tests were performed to determine the significant differences among sites for a given week. If a running weekly total was calculated for an ambient factor (precipitation etc.) sites were compared using the Kolmogorov-Smirnov (K-S) two sample nonparametric test. This procedure tested the null hypothesis that samples for two different sites come from identical distributions. T-tests are used to test for site differences if the variable of interest is only measured on the site as a whole rather than on each plot within a site. This was used for precipitation, relative humidity, photosynthetic active radiation, and air temperature 30 cm above the ground.

### Progress

#### Air Temperature (2 meters above the ground.)

Air temperature has a substantial influence on the rate of physiological processes such as photosynthesis, cell division and elongation, chlorophyll synthesis, and enzymatic activity (Kramer and Kozlowski 1960). Thus, differences in air temperature between sites or from one year to the next could have significant effects on vegetation growth and development.

The amount, composition, and distribution of vegetation are known to affect air temperature. In forests this effect is greatest at the soil

surface and within the canopy and least above the canopy. Thus, air temperatures which are recorded above the canopy of the red pine plantation should be independent of any ELF-induced effects on growth or development. As the tree crowns approach the level of the air temperature sensors on the plantation, trees can then be cleared to minimize crown effects. However, air temperatures in the pole-sized trees may not be independent of ELF fields. ELF fields could affect foliage production which in turn alters insolation at the soil surface as well as overall radiation budgets beneath the canopy. Comparisons of the two stand types (pole-sized and plantation) before and after antenna activation should indicate whether air temperature in the pole-sized tree plots is independent of ELF effects.

#### Missing Data Replacement

Due to down time at the platforms, air temperatures were not recorded for a number of weeks on the antenna and ground sites (Figure 2.2). These sites are located approximately one half mile from each other and have similar topographic features. Thus, it is felt that the weekly average air temperatures on one site could be used for missing average air temperatures on the other site. Tests were made to determine whether significant differences in air temperature exist between the antenna and ground plantations. Site ( $p = .69$ ) and site-week interactions ( $p = .06$ ) were not significantly different. However, the probability level ( $p = .06$ ) of the site-week interaction was close enough to the .05 significance level to warrant a more detailed inspection of the weekly air temperature between the sites. Examination of the data showed average weekly air temperature differences between the antenna and ground sites during the growing season (April 12 - Oct. 30) to be 0.1 degree Centigrade and the average absolute difference was 0.3 degrees centigrade. These

differences are at the sensor's precision limits, thus weekly air temperature from one site could be used for missing measurements from the other site. However, since air temperatures on a given plot within a site cannot be transferred to another plot/site combination, weekly average air temperature replacement was only used in multiple range testing, graphs, and growing season average temperatures. Site comparisons will only use actual recorded values from the sites. Average weekly temperatures from the ground site will also be used for missing air temperatures on the antenna pole-sized tree stand types, since differences between antenna stand types ( $p = .11$ ) and stand type-week interactions ( $p = .62$ ) were not significantly different.

#### Monthly Summaries

Monthly average temperature for all sites and treatments are presented in Figure 2.3. Monthly average temperatures did not exceed  $0^{\circ}\text{C}$  until April. The highest monthly temperature was recorded in July. The control site was consistently warmer than the other two sites over the 11 month recording period.

Average weekly temperatures during the 1985 growing season varied the most in April and September and least in July (Figure 2.4 - 2.5). The increase in temperature from the first week to the second week (April 22) on the growing season, averaged  $11.8^{\circ}\text{C}$  over all the sites. The April 22 average weekly temperature on the control site was not exceeded until the June 30 weekly average (refer to average weekly air temperature summaries (Appendix B, Tables 3-4)).

#### Ground vs. Control Comparisons

The control pole-sized tree plots had the highest average temperature ( $13.2$  degrees) over the entire growing season whereas, the antenna and

FIGURE 2.3

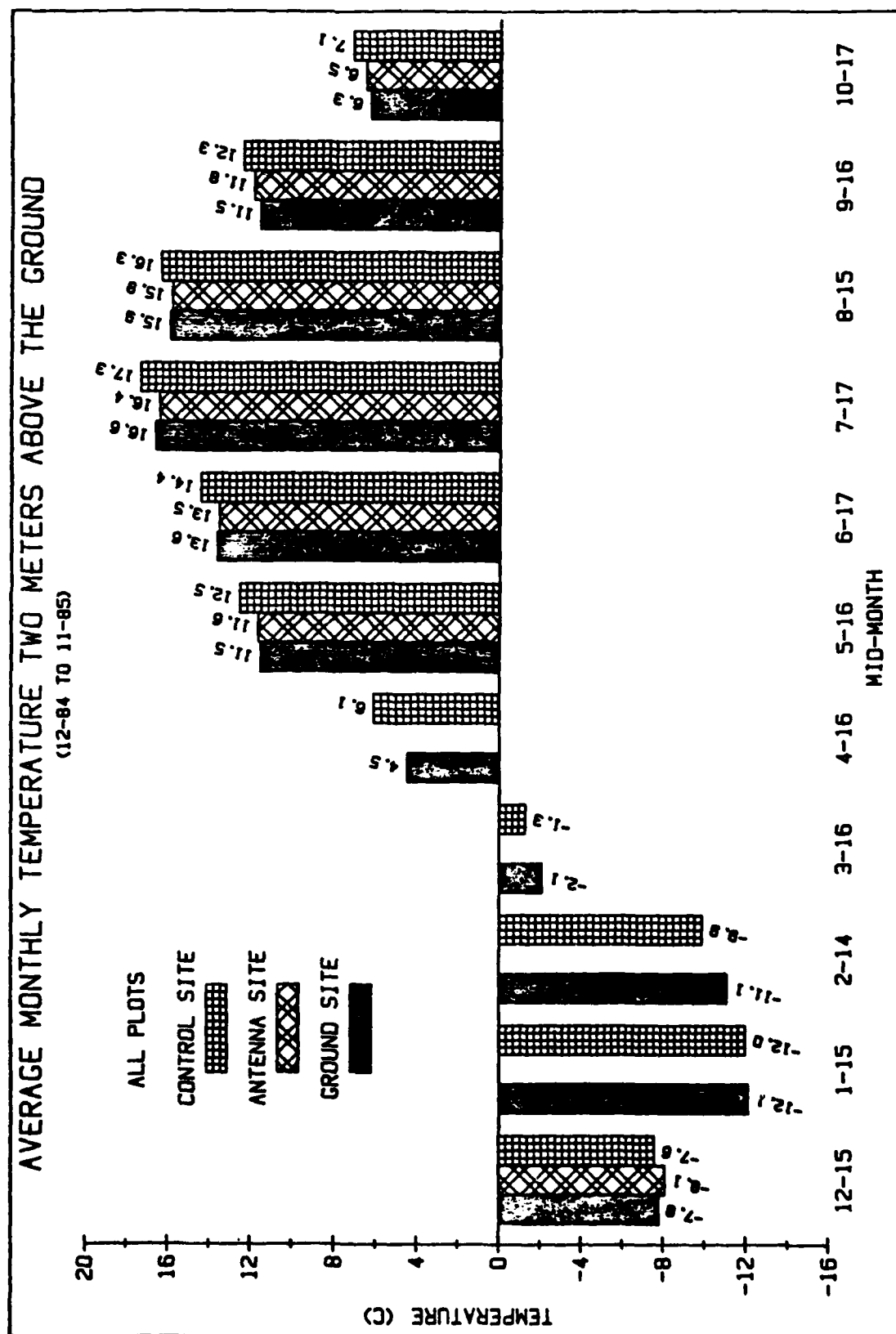


FIGURE 2.4

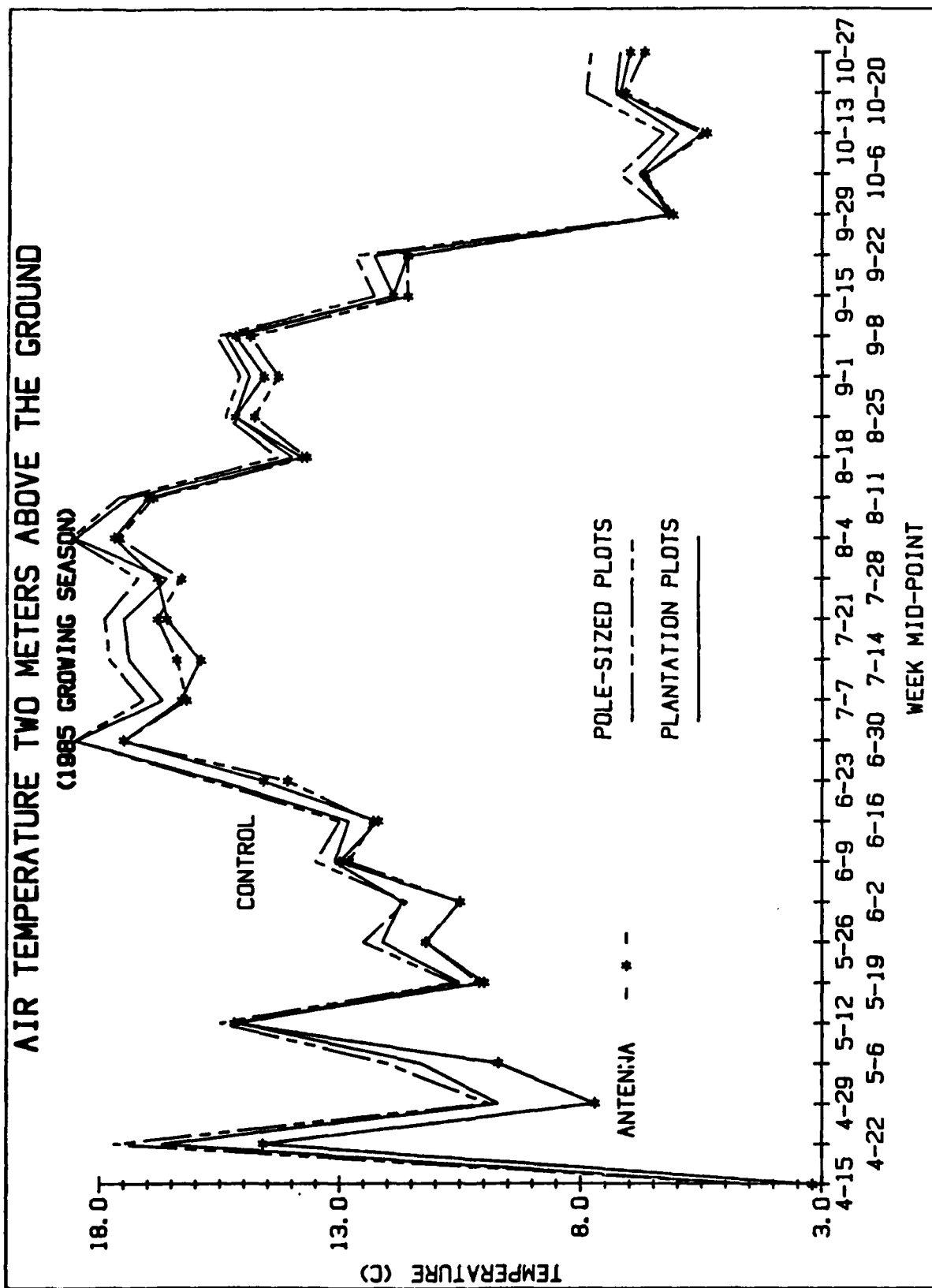
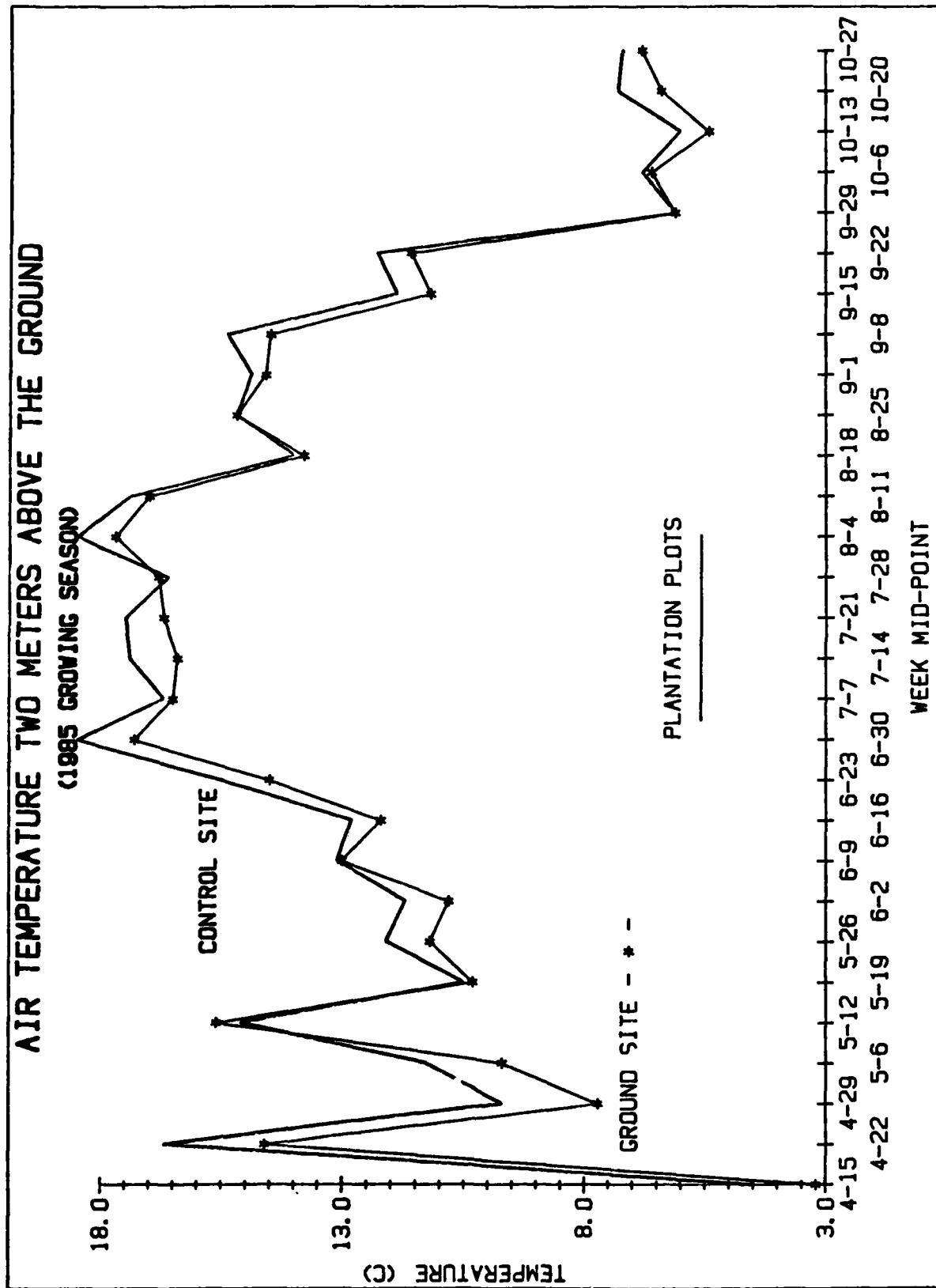


FIGURE 2.5





ground had average temperatures near 12.2°C (Appendix B, Tables 3 and 4). Comparison of the control and ground weekly temperatures indicated significant differences between sites ( $p = .00$ ). A multiple range test showed that differences between sites were significant throughout the growing season, but differences between the two sites tended to be greatest in the first four weeks of the recording period (Figure 2.6).

#### Antenna vs. Control Comparisons

Tests were performed to compare average weekly air temperature between the control and antenna sites with the results shown in Table 2.1

**Table 2.1 Comparison of weekly air temperatures at the antenna and control sites.**

<u>Factor</u>	<u>P-Value</u>
Site	.029
Stand type	.153
Stand type x site	.031
Week	.000
Week x site	.000

Due to the significant differences in the stand type-site interactions, sites were compared individually by stand type. Pole-sized tree plots at the control had significantly higher ( $p = .00$ ) temperature than the antenna site and differences were greatest early in the season (Figure 2.7). The control versus antenna plantation comparison did not show a significant site difference ( $p = .08$ ). This analysis did not include the air temperatures from the first four weeks of the season (data was missing from the antenna site) which tended to have the largest differences (Figure 2.8). If these weekly averages could have been included, site differences would probably have been similar to those of the ground and control.

Average weekly temperatures were also used to compare the sites by computing and summing growing degree days or heat sums. These values were

FIGURE 2.6 CONTROL-GROUND AIR TEMP. (PLANTATION)

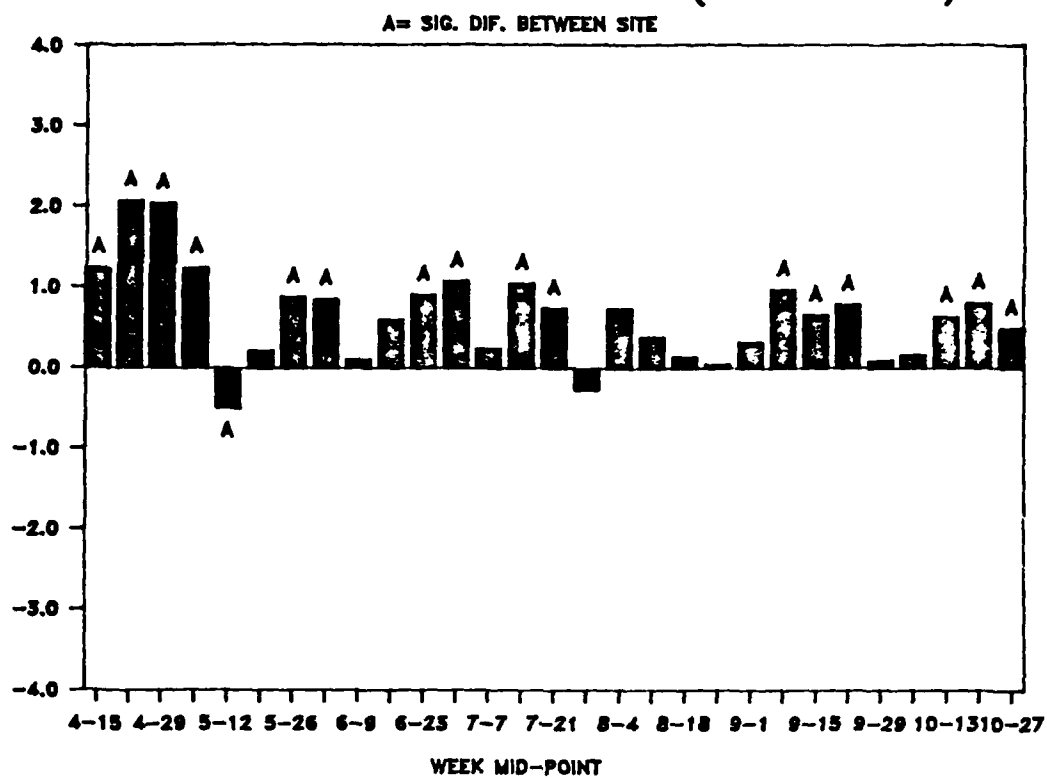


FIGURE 2.7 CONTROL-ANTENNA AIR TEMP. (PLANTATION)

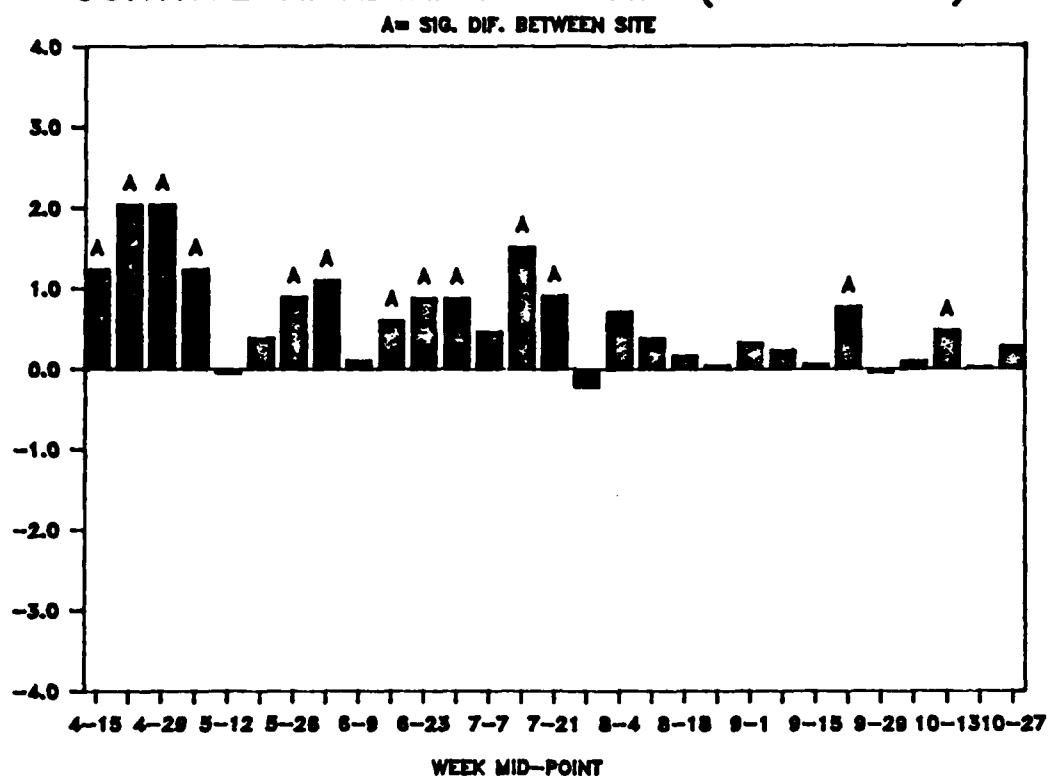
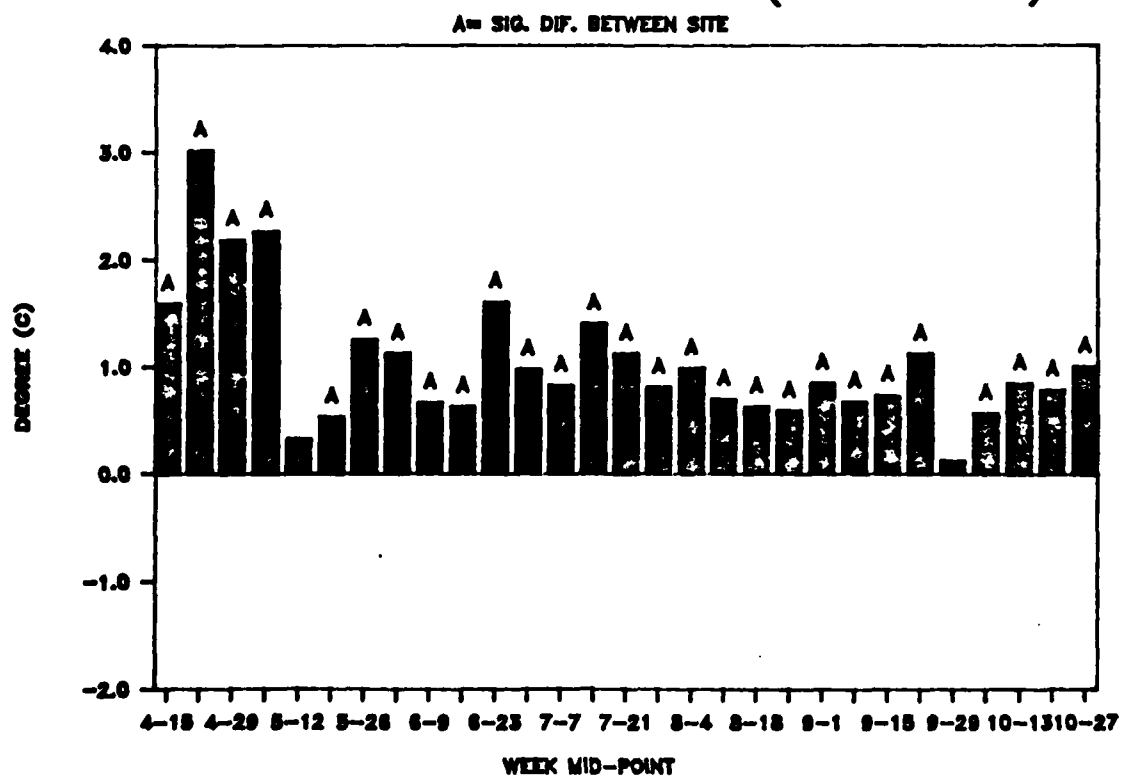


FIGURE 2.8 CONTROL-ANTENNA AIR TEMP. (POLE-SIZED)



calculated using the following equation.

$$\text{GDD} = (\text{Awt} - T) * \#Dw$$

where

GDD = growing degree days  
 Awt = average weekly temperatures  
 T = a threshold temperature (4.4°C for this study)  
 #Dw = number of days in week  
       = summation from week to week

Growing degree days or heat sums using various threshold temperatures have been found to be well correlated with red pine shoot growth and initiation of hardwood shoot growth (Perala 1985, Buech 1976). The initial calculation of growing degree days for this study has been implemented with threshold temperatures of 4.4°C and the summation of the degree days begins the first day of the calendar year. Table (2.2) shows that growing degree days accumulate faster at the control than at other sites. By the end of October the pole-sized tree plots at the control had accumulated 209.1 more growing degree days and the plantation 124.0 more growing degree days than the antenna pole-sized tree plots and plantation plots respectively.

#### Soil Temperature (5 and 10 cm)

Soil temperature, like air temperature, has a direct influence on plant physiological processes. However, soil temperature also indirectly affects plant growth and development by affecting soil microorganisms responsible for such processes as rates of nutrient mineralization and organic matter decomposition. General climatic conditions such as incoming solar radiation, air temperature and precipitation, as well as the physical characteristics of the mineral soil are the main factors controlling soil temperature. However, organic matter decomposition, amount and timing of leaf fall, and ground flora composition also affect soil temperature. Due to the possible effects of the ELF system on microbial populations, leaf fall, decomposition rates, or other related factors, an assumption of independence

Table 2.2: Accumulated growing degree days.

WEEK MID-POINT	GROUND	ANTENNA PLANTATION	ANTENNA POLE-SIZED TREE PLOTS	CONTROL PLANTATION	CONTROL POLE-SIZED TREE PLOTS
4-15	15.8	15.8	15.8	25.4	27.1
4-22	87.1	86.9	86.9	111.3	119.8
4-27	110.0	109.8	109.8	148.6	158.0
5-6	141.6	141.4	141.4	187.7	203.3
5-12	219.9	216.6	216.5	262.5	280.8
5-19	260.6	256.0	255.9	304.7	323.9
5-26	308.2	303.6	303.3	358.6	380.1
6-2	352.7	346.4	345.9	409.1	430.6
6-9	412.5	406.2	404.8	469.7	494.2
6-16	466.9	460.5	460.1	528.4	553.8
6-23	537.6	531.4	527.8	605.5	632.9
6-30	627.7	622.9	619.5	703.2	731.4
7-7	712.2	705.9	702.0	789.4	819.8
7-14	795.9	786.3	785.4	880.5	913.0
7-21	882.0	871.2	871.6	971.8	1007.2
7-28	968.7	957.7	954.9	1056.7	1096.1
8-4	1061.6	1050.7	1046.9	1154.8	1195.0
8-11	1149.4	1138.5	1134.3	1245.3	1287.4
8-18	1215.1	1204.0	1198.9	1311.9	1356.4
8-25	1290.1	1279.0	1271.5	1387.3	1433.2
9-1	1361.2	1350.1	1340.4	1460.7	1508.1
9-8	1431.4	1425.5	1413.5	1537.8	1586.0
9-15	1479.1	1477.4	1463.7	1590.1	1641.4
9-22	1529.1	1527.5	1513.8	1645.7	1699.4
9-29	1540.4	1539.7	1525.4	1657.6	1711.9
10-6	1555.6	1555.6	1541.1	1674.1	1731.6
10-13	1562.2	1563.4	1548.1	1685.3	1744.5
10-20	1576.4	1583.0	1566.6	1705.1	1768.6
10-27	1592.5	1600.7	1582.7	1724.7	1791.8

between the ELF system effects and soil temperature can not be made.

#### Missing Data Replacement

Unlike average weekly air temperature, missing soil temperatures from the ground or antenna sites could not be replaced by the measured average weekly soil temperature value from the other site. Although no significant site differences were found between the ground and antenna (soil temperature 5 cm ( $p = .55$ ) and 10 cm ( $p = .31$ )) differences in site-week interactions for temperature at depths of 5 cm ( $p = .01$ ) were significant. Site-week interactions were not significantly different at the 10 cm depth ( $p = 0.07$ ). However, temperatures at this depth were consistently warmer on the antenna site. The average weekly difference (antenna - ground) was  $0.47^{\circ}\text{C}$  and the absolute average difference was  $0.50^{\circ}\text{C}$ . Given these conditions replacement of a missing weekly temperature with a weekly average temperature from the other site was not justified.

#### Monthly Summary

Monthly average soil temperatures (5 cm and 10 cm) are presented graphically in figures 2.9 through 2.12. Monthly average soil temperatures did not exceed  $0^{\circ}\text{C}$  until April. The coldest soil temperatures (5 cm and 10 cm) were recorded during February and the warmest temperatures were recorded in July, both on the plantation plots). Monthly variation in soil temperature was also greatest on the plantation plots compared to the pole-sized tree plots. For example, the difference between the highest and lowest monthly soil temperatures at a depth of 5 cm at the control pole-sized plots was  $16.5^{\circ}\text{C}$  compared to the plantation difference of  $19.2^{\circ}\text{C}$ . Except in May, the control site had consistently higher soil temperatures (5 cm and 10 cm) in pole-sized tree plots than did the antenna site.

FIGURE 2.9

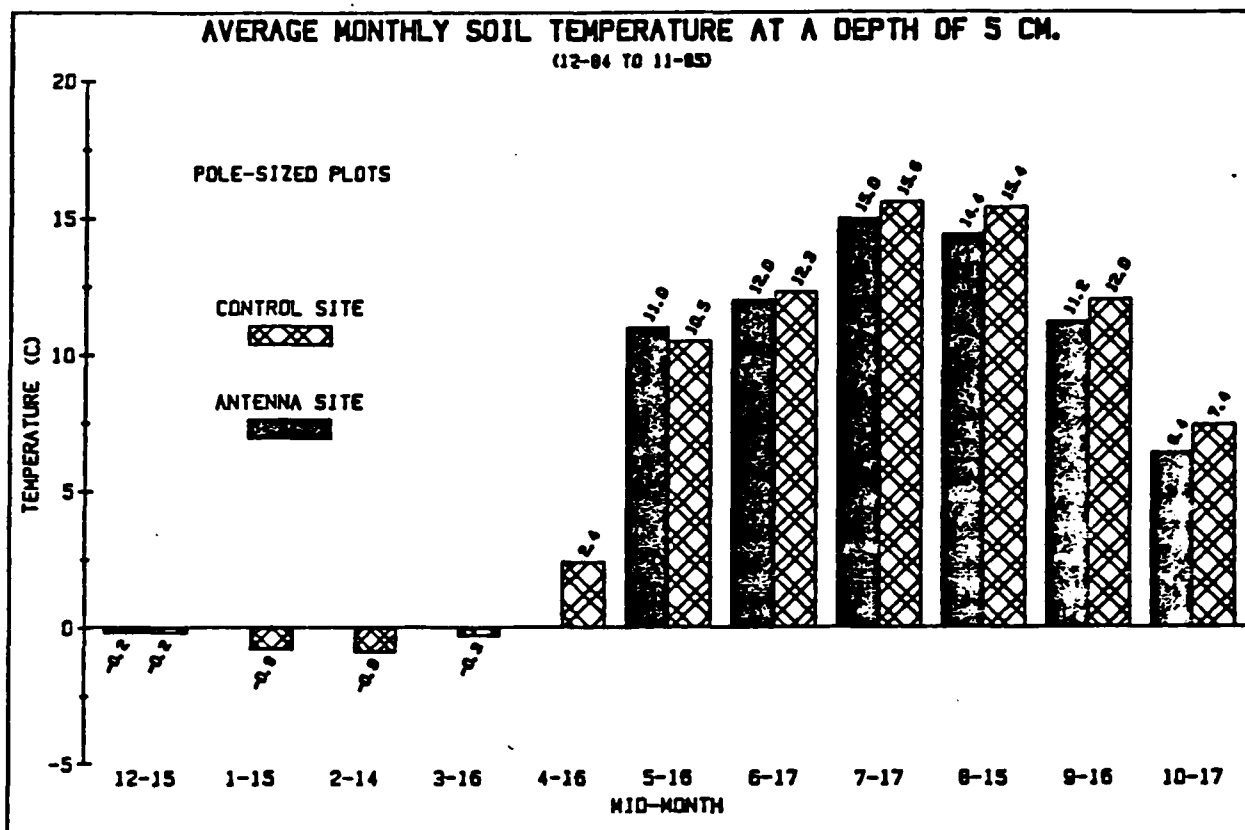


FIGURE 2.10

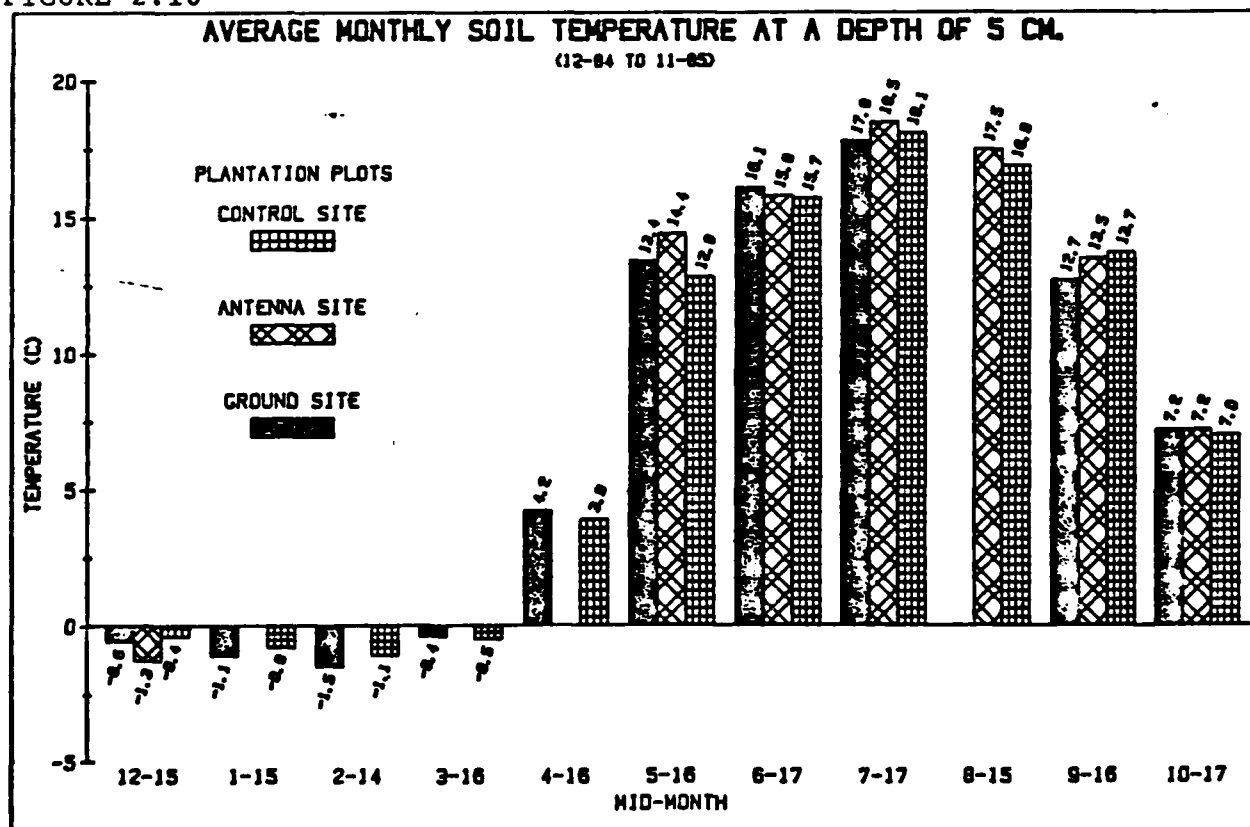


FIGURE 2.11

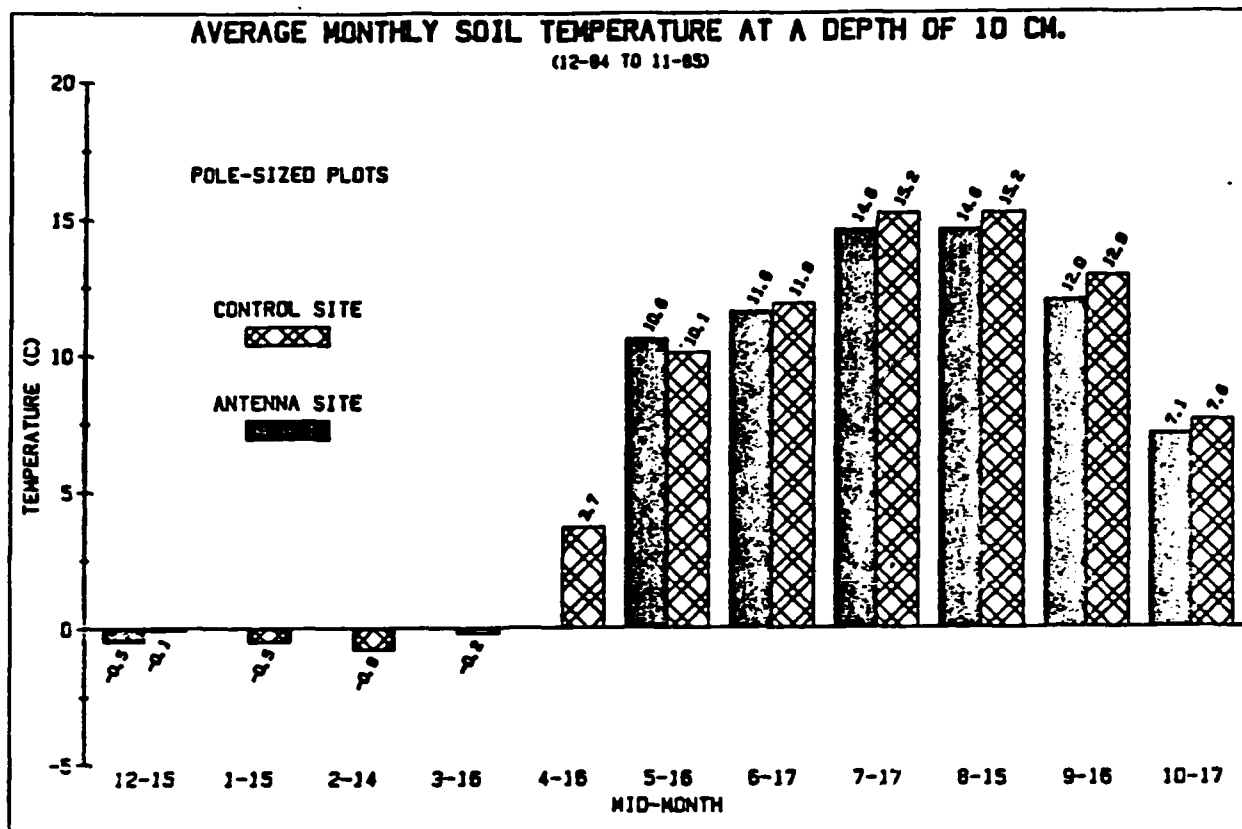
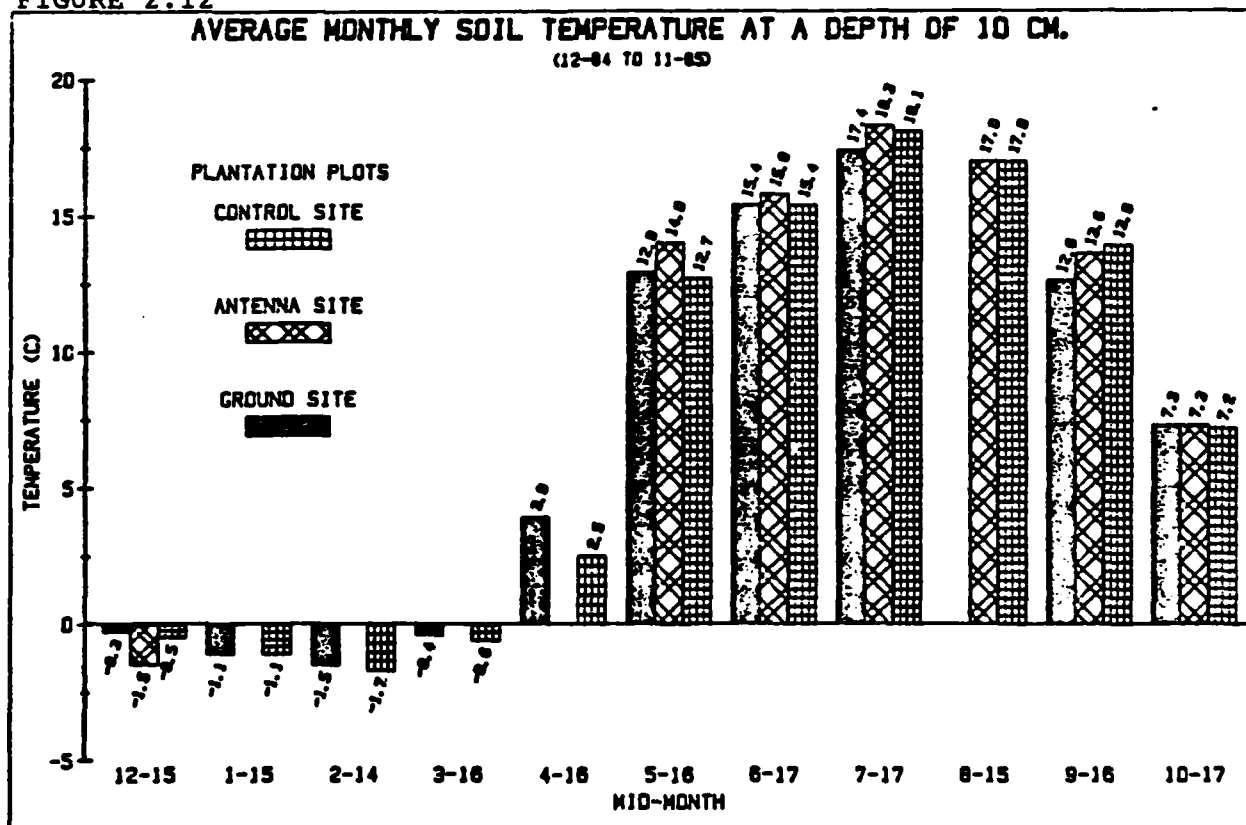


FIGURE 2.12





However, no site had consistently higher temperatures than the other sites in the plantation plots. Differences between sites were greatest between sites in May and least in October.

#### Ground vs. Control Comparison

Weekly average soil temperatures during the growing season for the ground and control plantations are presented in Figures 2.13 and 2.14 and in tabular form in Appendix B Tables 6 and 7. Figures 2.13 and 2.14 show that soil temperature at the control and ground plantations generally increases on a weekly basis between the weeks of April 15 and June 30. These level off and stabilize between June 30 and August 11, and decrease after the week of August 11.

Comparison of sites (Figures 2.13 and 2.16) indicate that soil temperature at the ground site was generally warmer than the control site during the spring (April 15 to June 16), but cooler than at the control site in the latter part of the growing season (June 30 to October 13). Significant differences between sites were not clustered in any specific time period of the growing season but distributed uniformly over the entire growing season. Average soil temperatures over the growing season could only be computed for the weeks in which both the control and ground sites had complete data (April 15 to June 16, June 30 to July 28, and September 8 to October 27). Soil temperature for the control plantation at a depth of 5 cm averaged 12.4°C compared to 12.5°C degrees centigrade for the ground site. Soil temperatures at 10 cm were 14.3 and 14.4°C respectively.

#### Antenna vs. Control Comparison

Figures 2.17 and 2.18 as well as the tables in Appendix B (Tables 8 and 9) present weekly average soil temperatures for the antenna and control sites. At both sites soil temperature on the pole-sized tree plots tended to increase over a longer time period than did the plantation plots (April 15

FIGURE 2.13

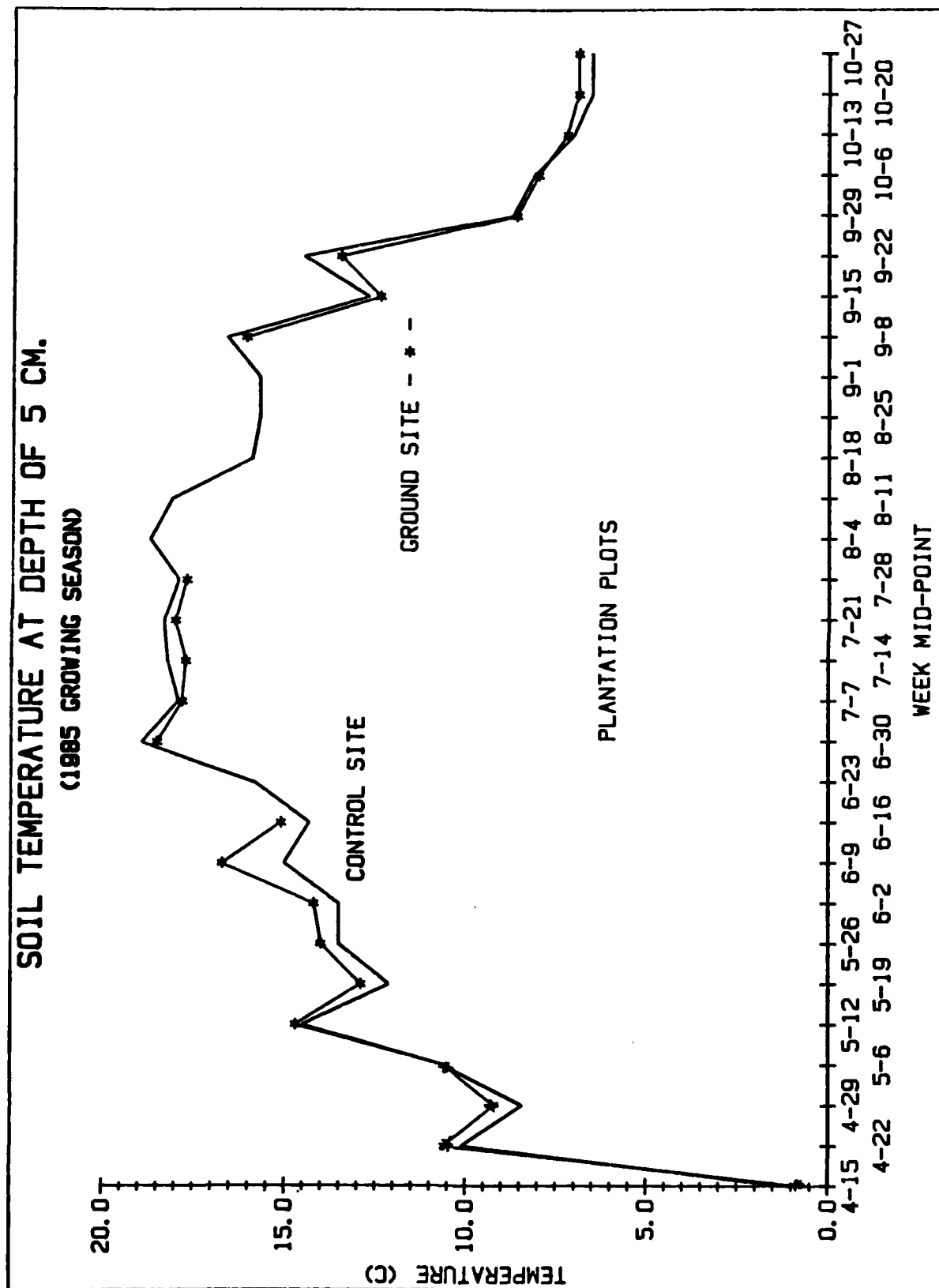


FIGURE 2.14

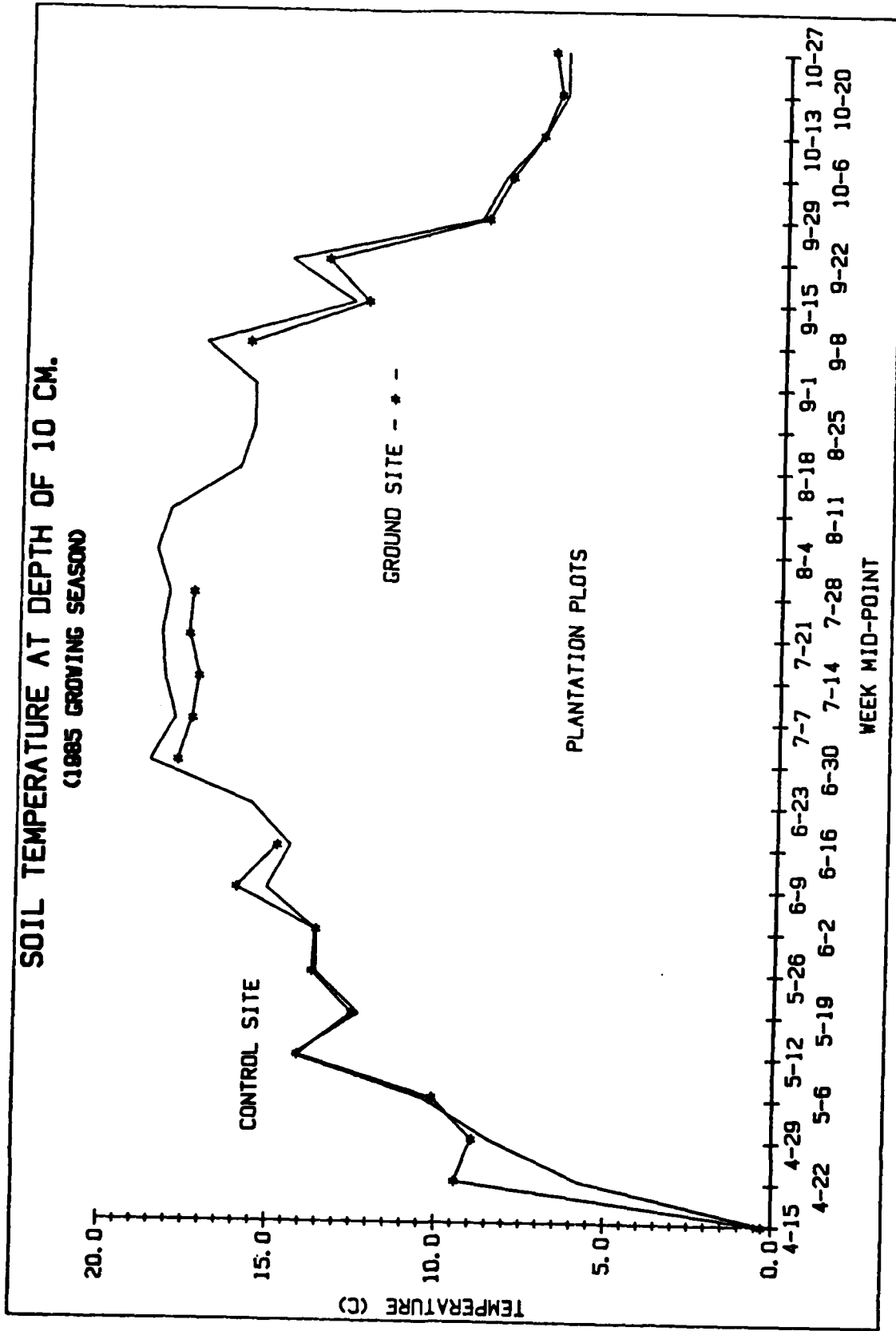


FIGURE 2.15 CONTROL-GROUND SOIL TEMP. 5CM

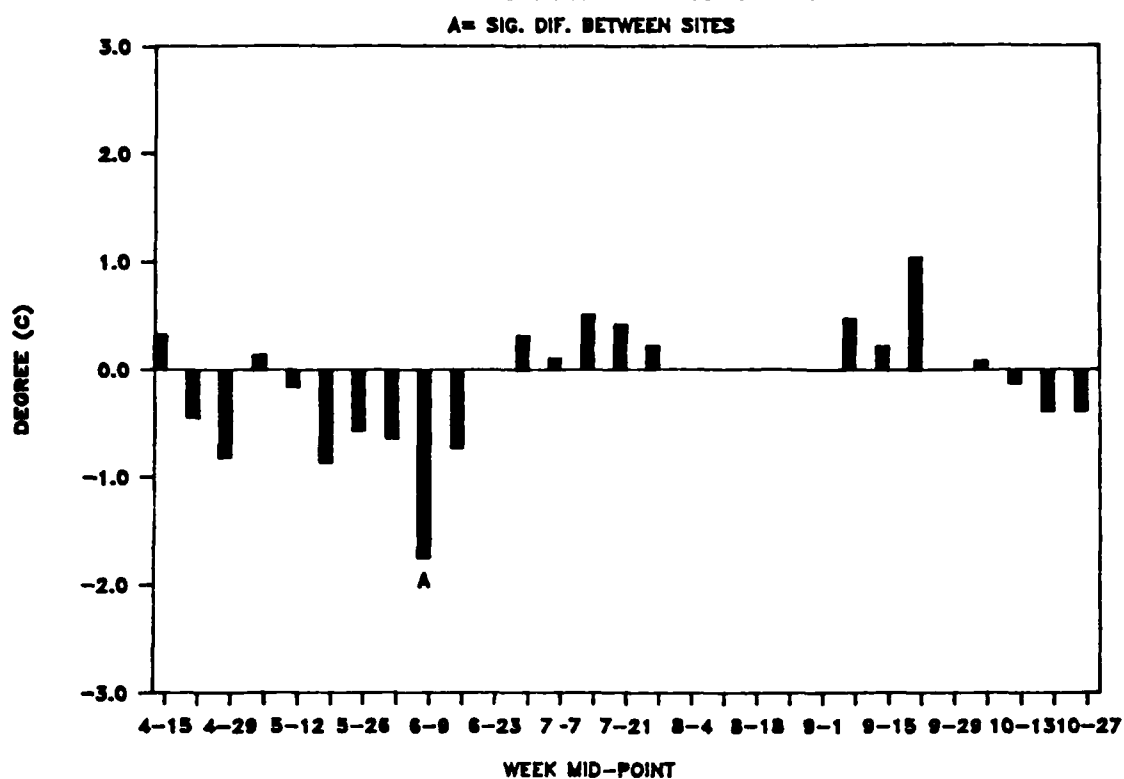


FIGURE 2.16 CONTROL-GROUND SOIL TEMP. 10CM (PLANT.)

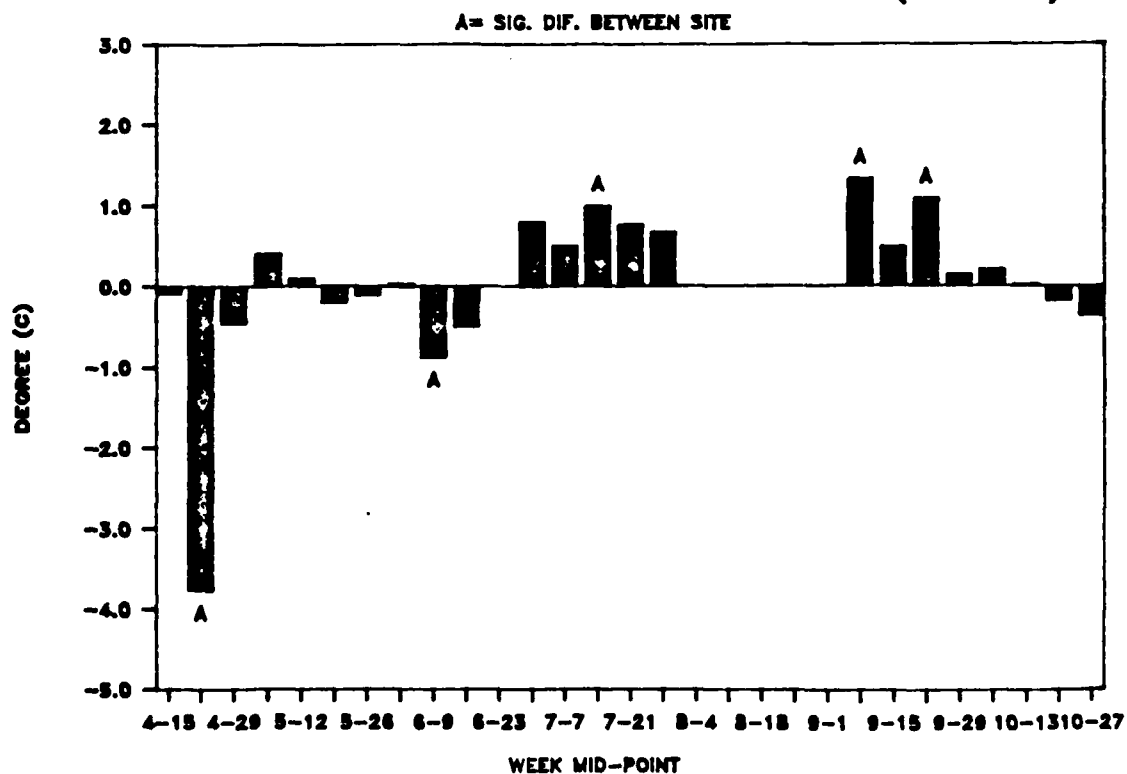


FIGURE 2.17

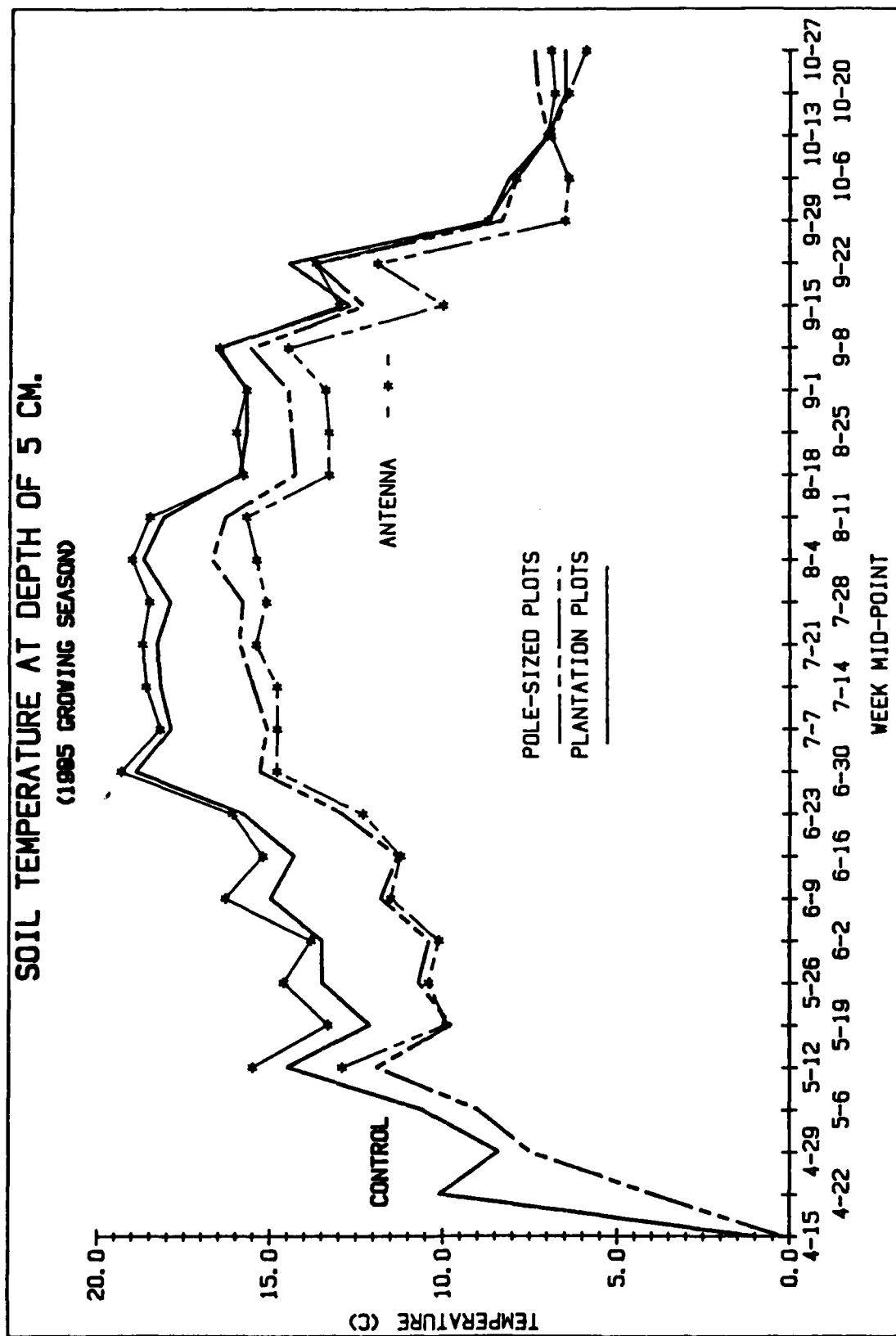
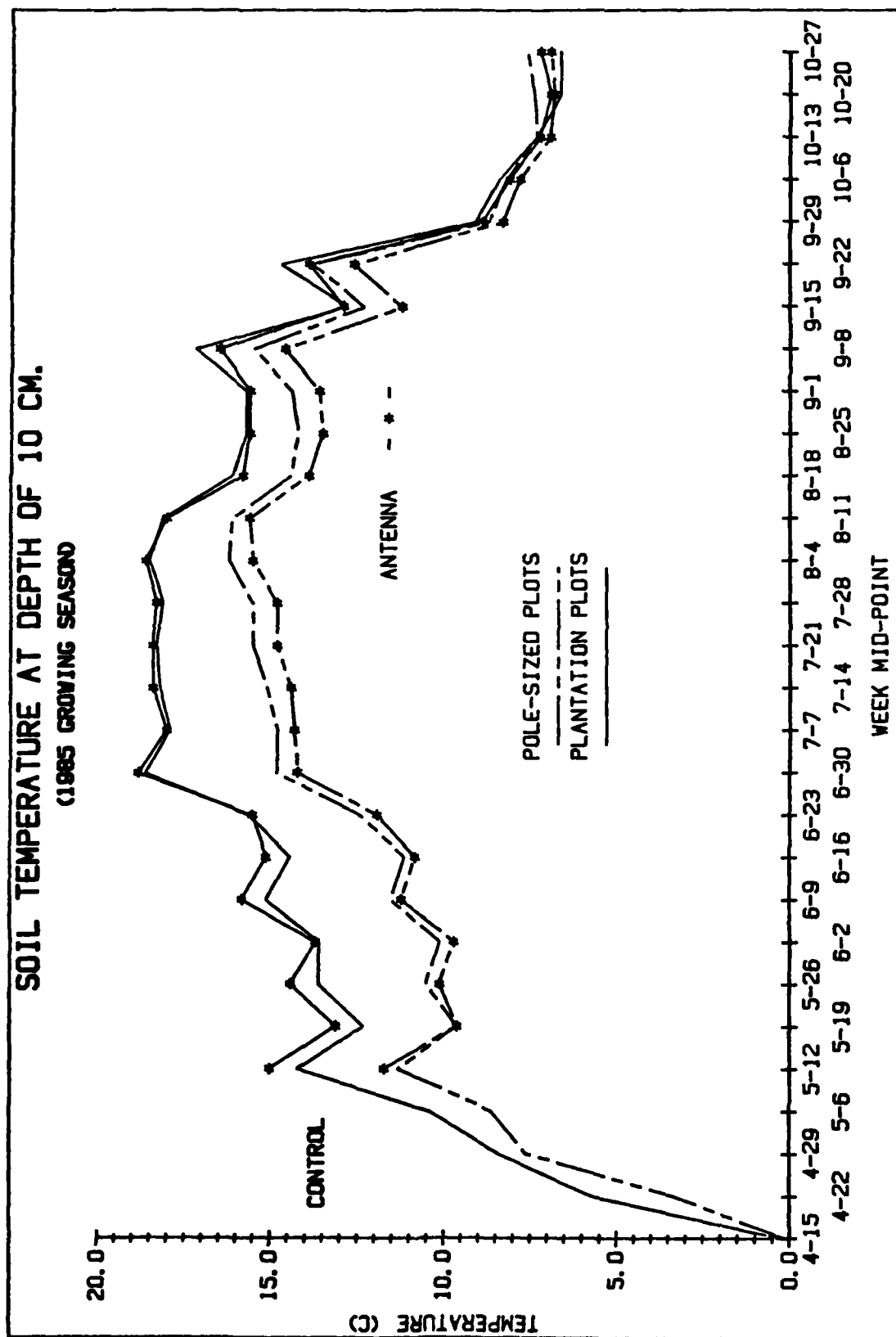


FIGURE 2.18



through August 11 compared to April 15 through June 30). Furthermore, soil temperature in the pole-sized tree plots never stabilized as in the plantation plots. Soil temperatures were higher in the plantations compared to the pole-sized tree plots throughout the spring and summer. However, by the middle of September, differences between the plantation and pole-sized plots were virtually nonexistent.

Comparisons of soil temperatures between antenna and control sites at each depth are shown in Table 2.3.

Table 2.3. Soil Temperature 5 cm and 10 cm.

<u>Factor</u>	<u>P-Value</u>	
	<u>5 cm</u>	<u>10 cm</u>
Site	.48	.10
Stand type (plantation pole-sized plot)	.07	.01
Treatment x site	.46	.44
Week	.00	.44
Week x site	.00	.00
Stand type x week	.00	.00
Stand type x week x site	.25	.76

Since stand type-site and stand type-week-site interactions were not significantly different, the analysis was not applied for each individual stand type (plantation or pole-size tree) group.

Figures 2.19 through 2.22 show that the plantation soil temperature at the antenna site was higher than the control site during the first half of the growing season but cooler in the latter half of the growing season. However, in the pole-sized tree plots the control site maintained warmer temperatures during the entire growing season. Site differences between soil temperatures in the plantations for a given week were greatest during the spring whereas differences were greatest in the pole-sized tree plots during the September. Significant differences between sites for each depth were found during these respective times.

FIGURE 2.19 CONTROL-ANT. SOIL TEMP. 5 CM (PLANT.)

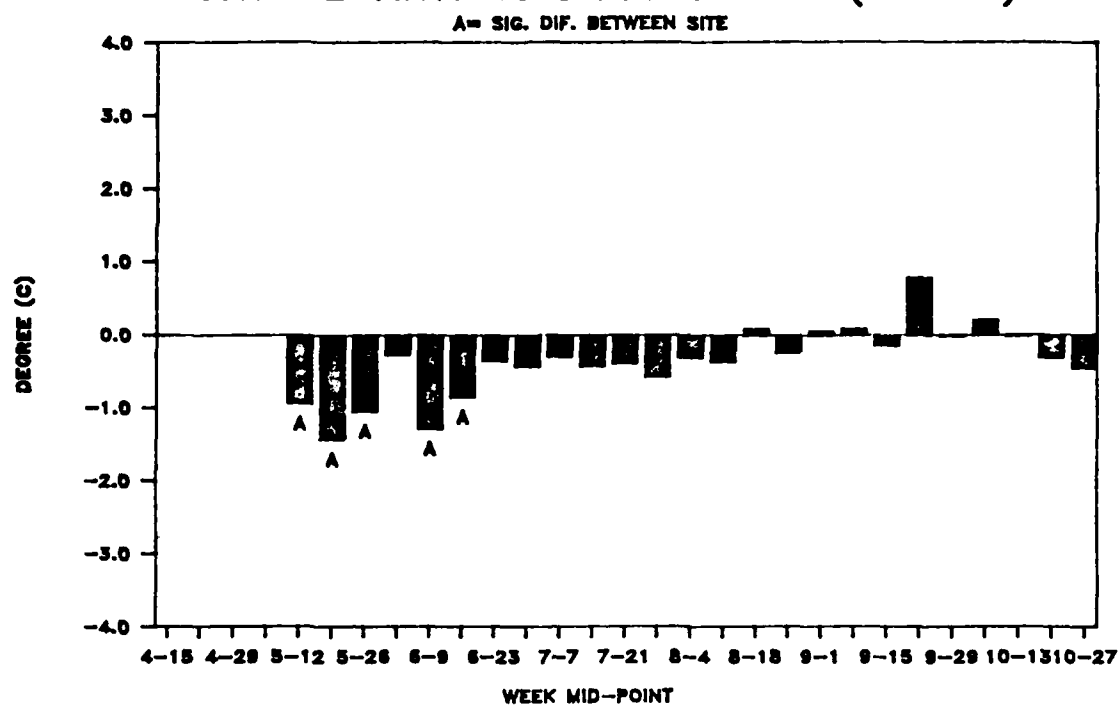


FIGURE 2.20 CONTROL-ANT. SOIL TEMP 5 CM (POLE-SIZE)

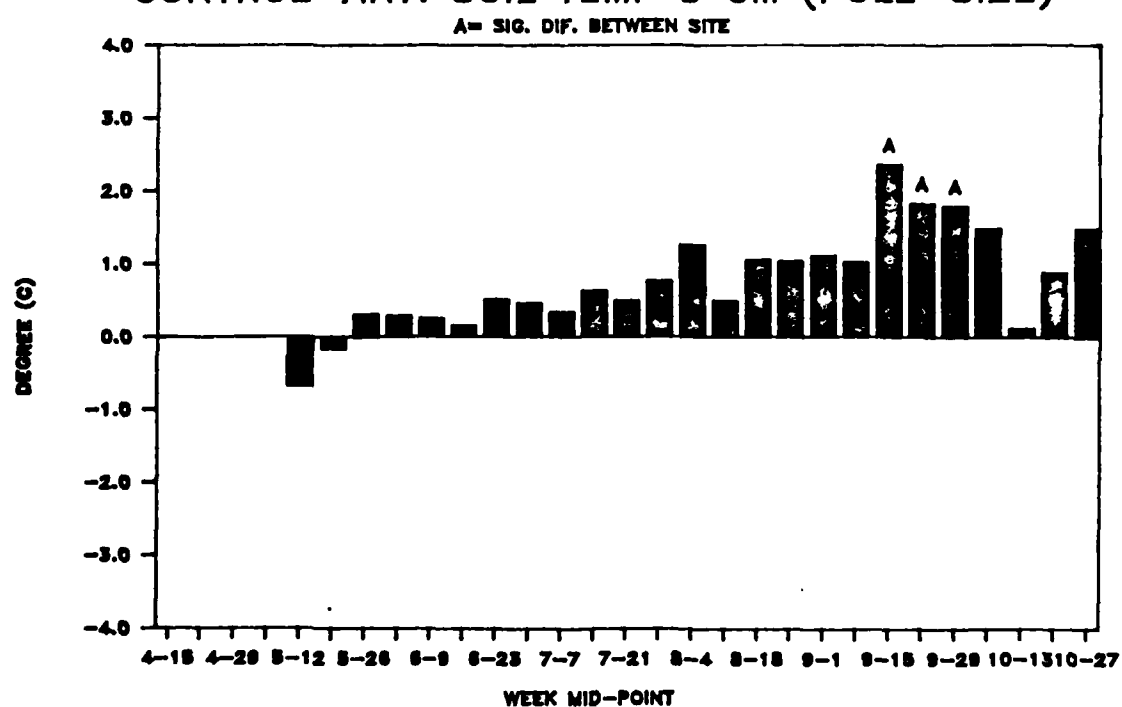




FIGURE 2.21

## CONTROL-GROUND SOIL TEMP. 5CM

A= SIG. DIF. BETWEEN SITES

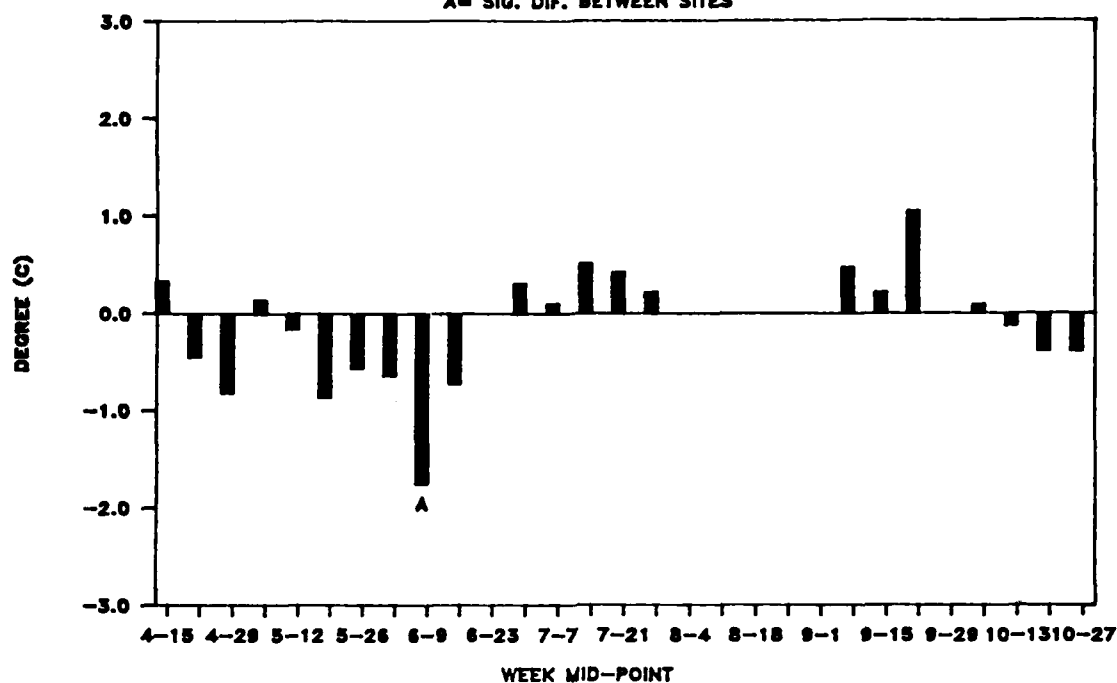
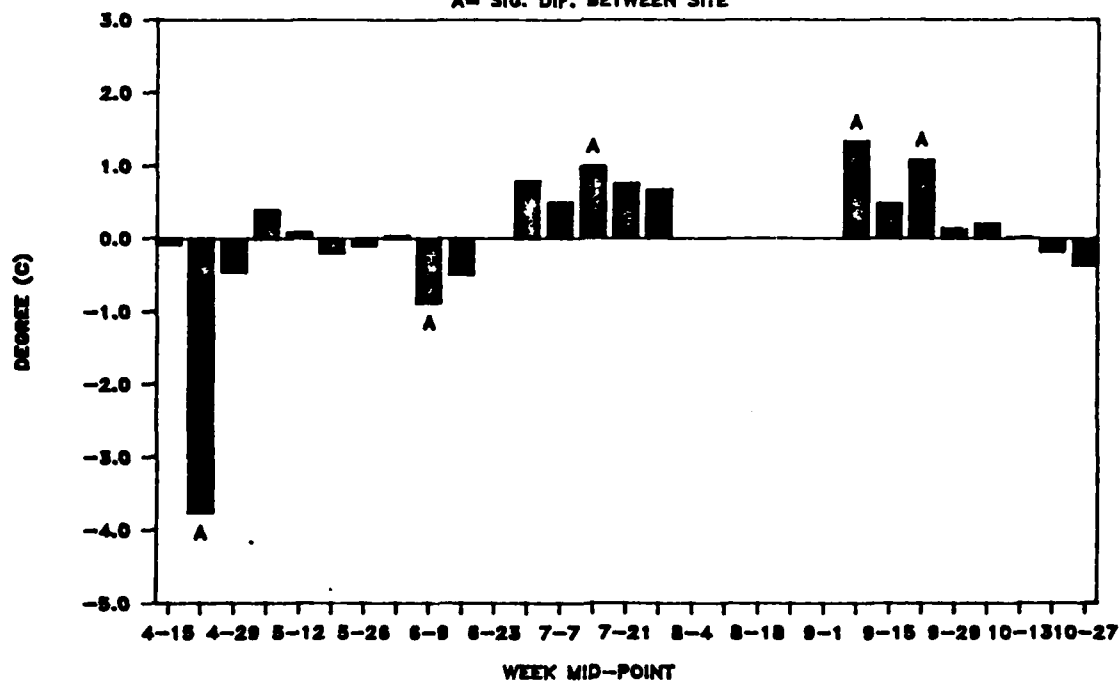


FIGURE 2.22 CONTROL-GROUND SOIL TEMP. 10CM (PLANT.)

A= SIG. DIF. BETWEEN SITE



#### Soil Moisture (Depth of 5 and 10 cm).

The amount and availability of soil water is considered a key factor in determining forest site productivity. Water in the soil is the primary vehicle for transportation of nutrients to the plant, and is a reagent in photosynthesis, as well as an essential constituent of cell protoplasm. Apical and radial growth have been shown to be highly correlated to soil water supply (Zahner 1968). Thus, soil moisture will be an extremely important ambient variable to monitor in the study. The amount and availability of water in the soil is determined by the inputs to the system (precipitation), the physical characteristics of the soil, the structure and composition of the vegetation occupying the site, and the climatic factors (light intensity, wind, etc.) which control evapotranspiration losses. Changes in growth, leaf area, timing of leaf fall, or community structure due to the ELF system could affect evapotranspiration, and therefore, soil moisture must be assumed to be a nonindependent variable.

#### Missing Data Replacement

A replacement of missing soil moisture information during the growing season on the antenna and ground sites was evaluated in the same manner as was air temperature discussed previously. Although significant differences in soil moisture levels between the ground and antenna sites (5 cm or 10 cm) did not exist, differences between the site weekly soil moisture averages were not small enough to justify the replacement of missing averages on one site with averages from the others. For example, the ground site had consistently higher moisture levels at depths of 5 cm than did the antenna. The average weekly difference and the absolute average difference was 3.4% for this depth. This large and consistent difference indicated that the sites were too dissimilar for missing data replacement.

#### Ground vs. Control Comparison

Due to the low temperature of the soil in the winter, soil moisture readings in the winter months measured by galvanic moisture probes are unreliable and only site comparisons during the growing season could be made. Average weekly soil moisture is given for the control and ground plantation in Figures 2.23 and 2.24 and in Appendix B (Tables 11 and 12). The lowest soil moisture averages were recorded the week of April 29 and August 4 for both sites. During the week of April 15 to June 9 the ground site appears to have a higher soil moisture content than the control. The control had higher average soil moisture during the latter part of the growing season at depths of 5 cm and for the entire growing season at depths of 10 cm. Figures 2.25 and 2.26 show the significant differences between sites by week. Although differences in moisture content between sites for a given week were as high as 2 to 3 percent, variability within the sites was high enough that these differences were not significant. For example, the standard deviation for the control and ground sites for the week of April 29 at a depth of 10 cm was 1.80 and 2.05 respectively. The moisture level difference between the two sites was 1.9 percent for that week and was not significantly different at the .05% level.

#### Antenna vs. Control Comparison

Average weekly soil moisture is presented for the control and antenna site in Figures 2.27 and 2.28 as well as in Appendix B (Tables 14 through 17). Soil moisture averages were consistently higher in the plantation plots compared to pole-sized plots. Generally, the control had higher moisture levels than the antenna sites, except at the 5 cm depth during the week of July 14 through the week of August 25. Comparisons of soil moisture at these sites are given below.

FIGURE 2.23

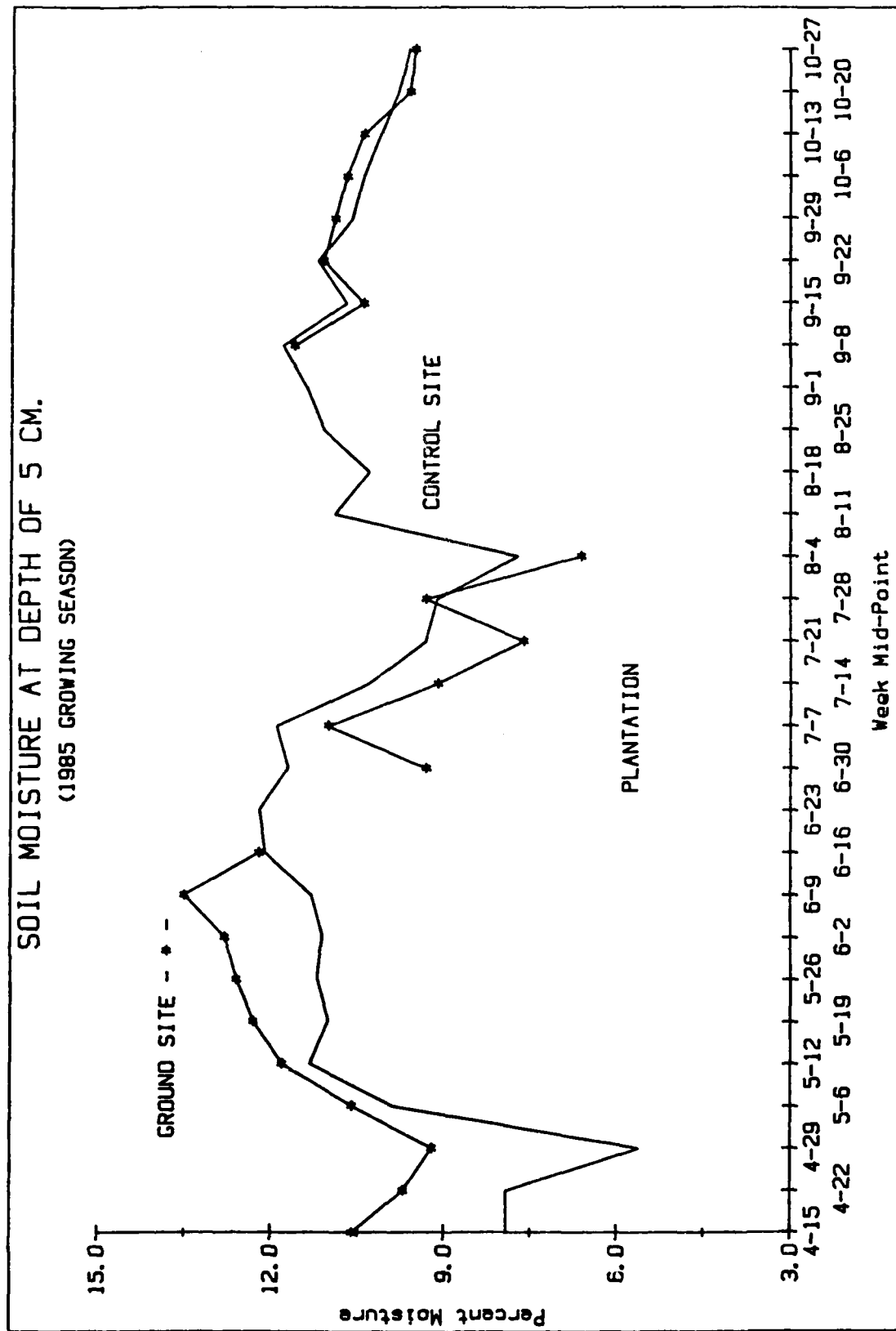


FIGURE 2.24

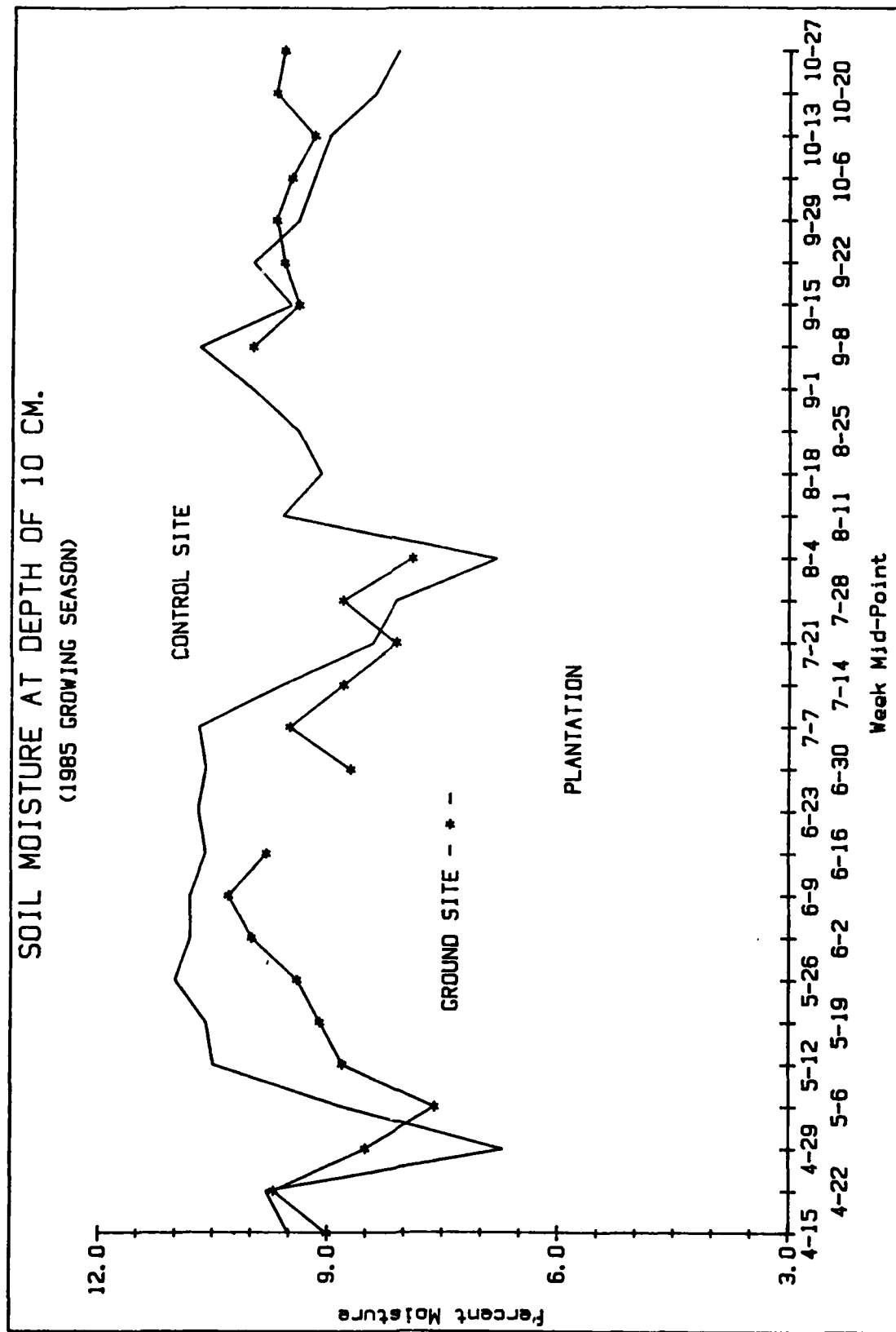


FIGURE 2.25 CONTROL-GROUND SOIL MC% 5 CM (PLANT.)

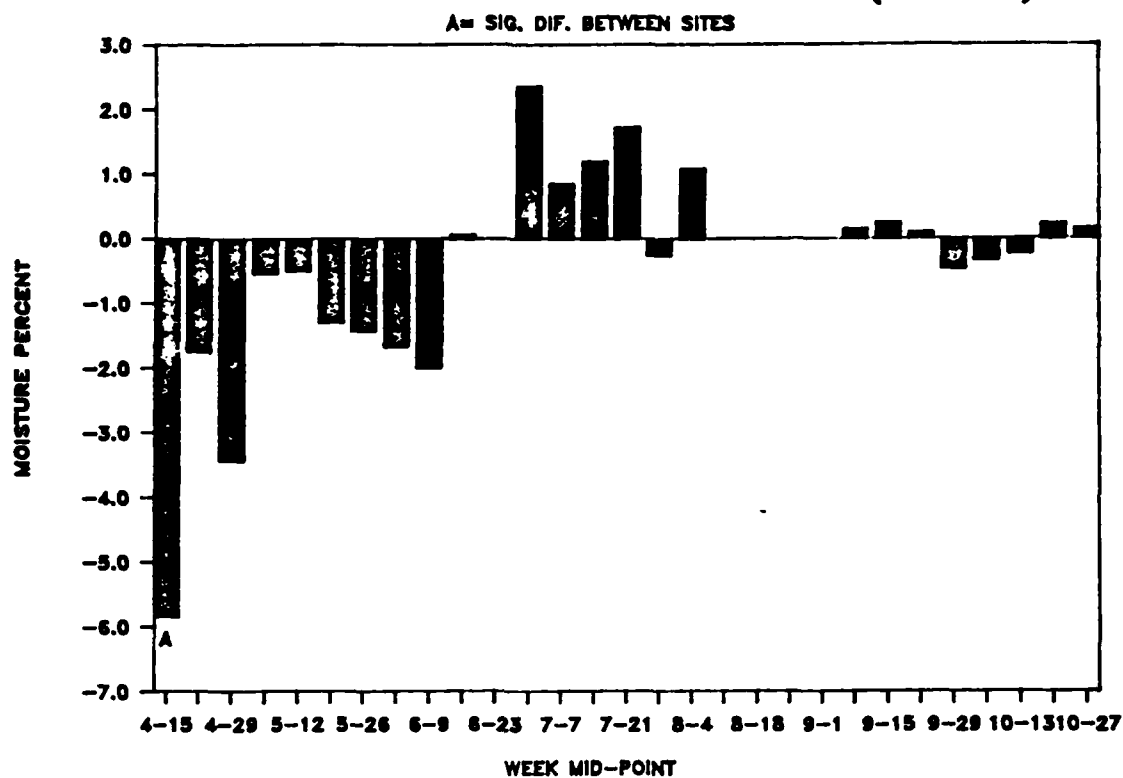


FIGURE 2.26 CONTROL-GROUND SOIL MC% 10 CM (PLANT.)

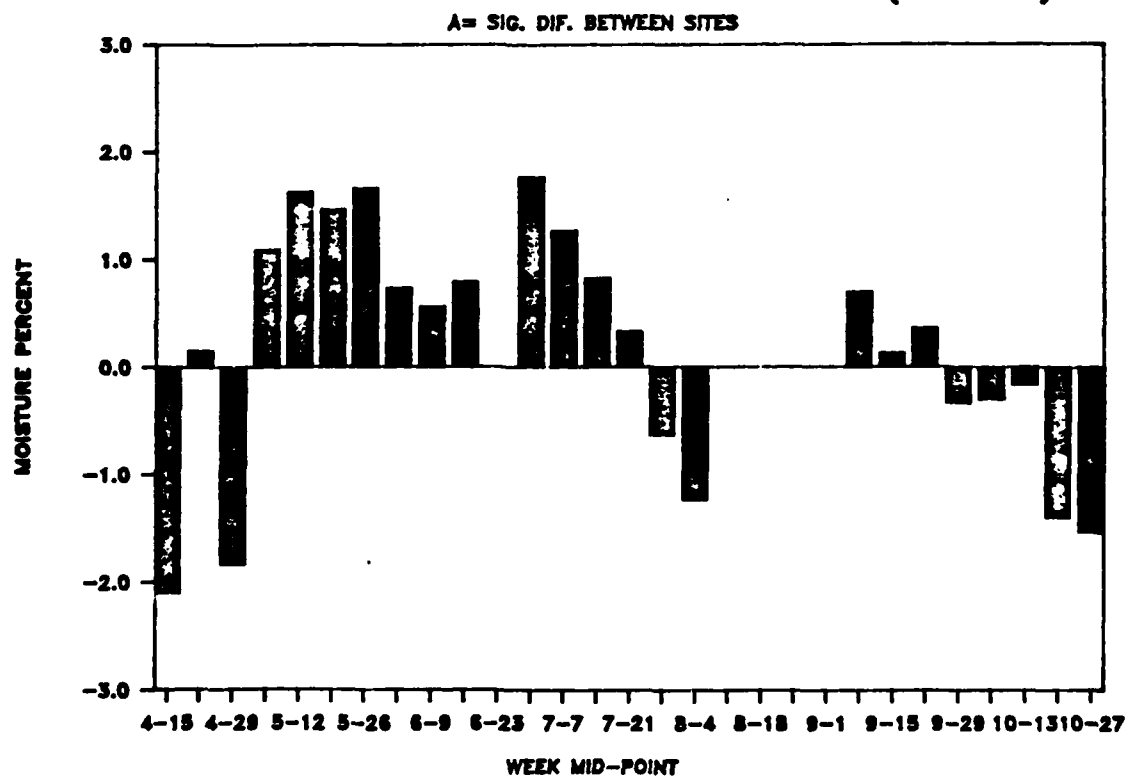


FIGURE 2.27

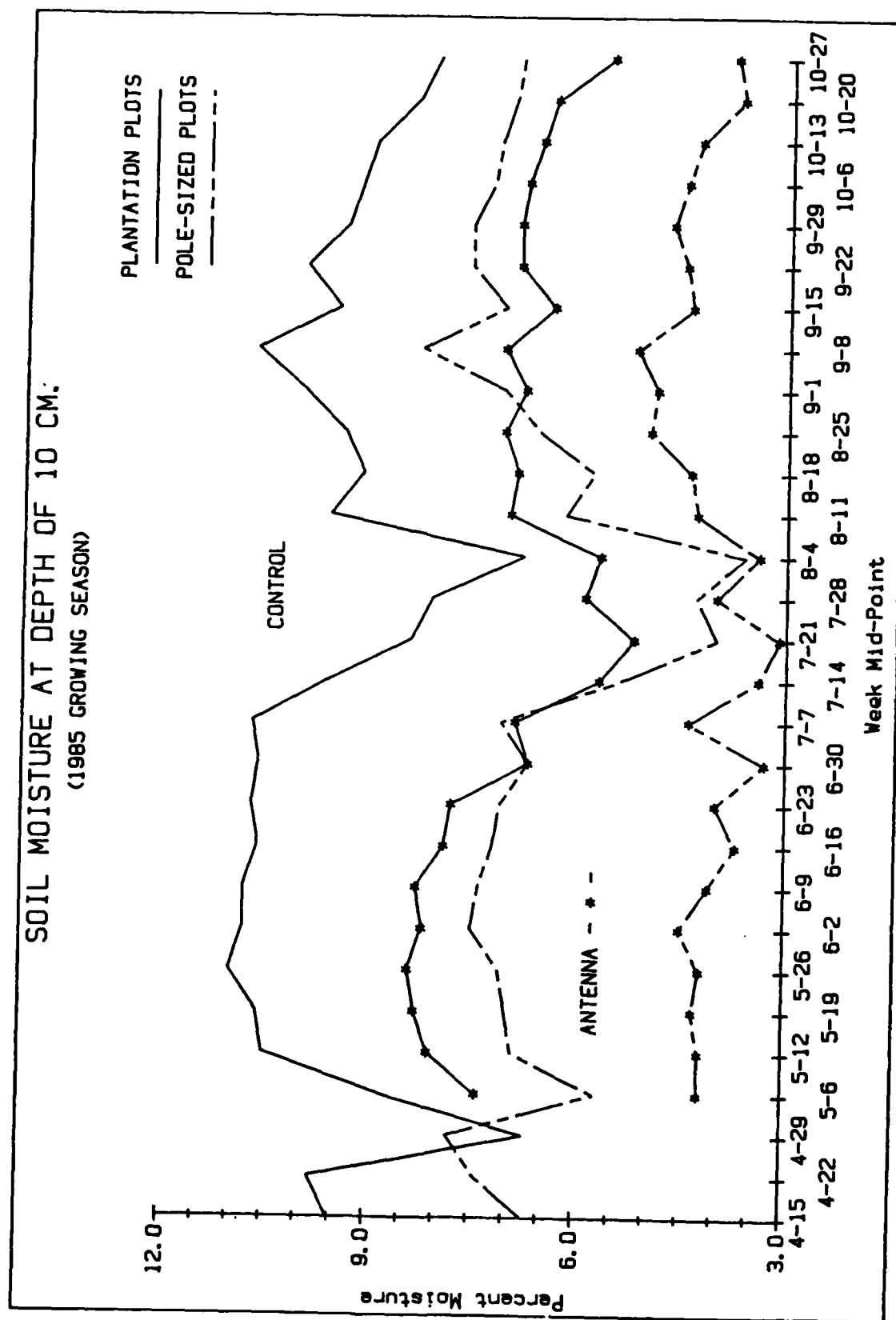


FIGURE 2.28

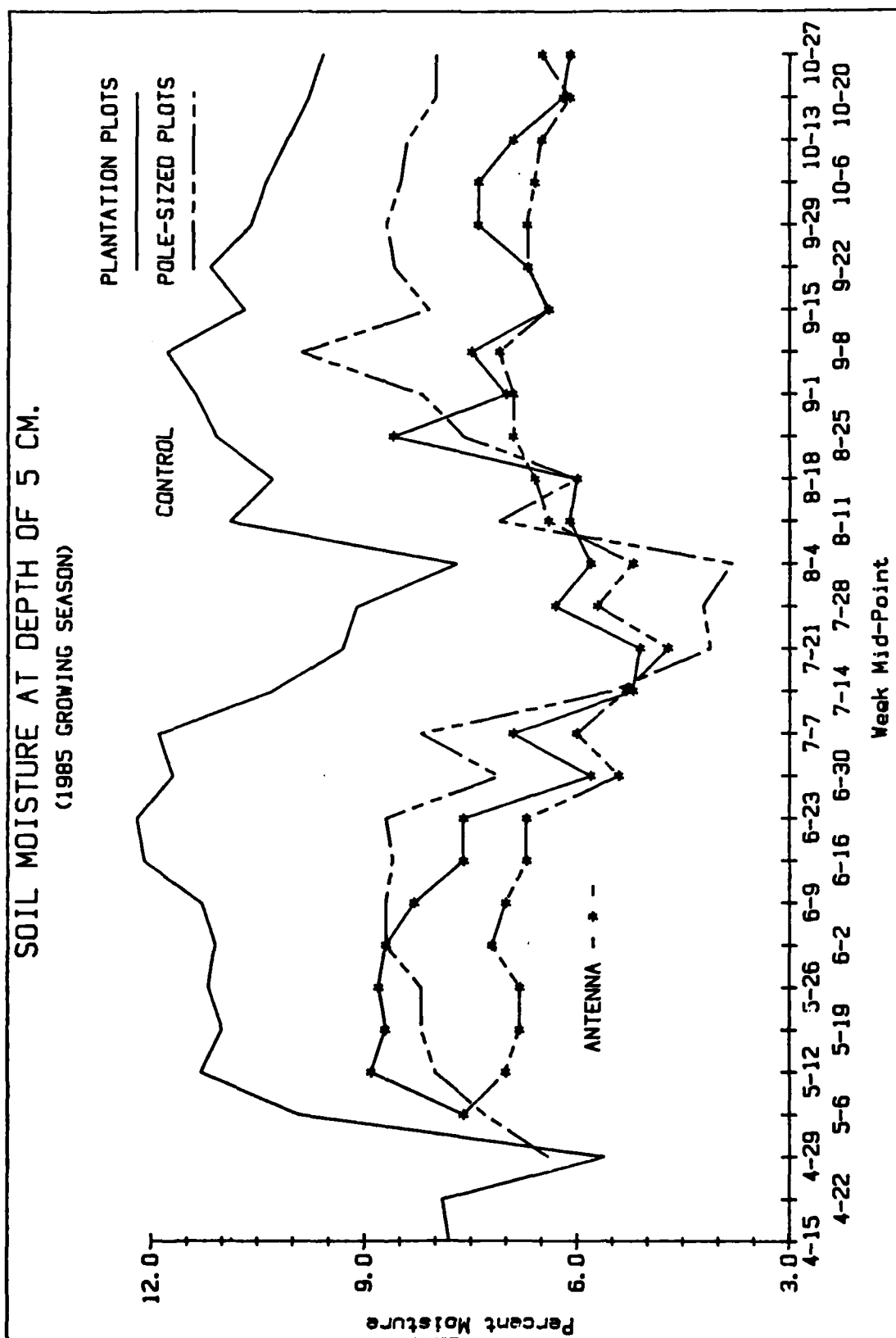




Table 2.5. Soil moisture at 5 cm (all plots).

	<u>Factor</u>	<u>P-Value</u>
Site		.55
Stand type		.31
Stand type x site		.12
Week		.00
Site x week		.01
Stand type x week		.00
Stand type x week x site		.10

Table 2.6. Soil moisture 10 cm (plantation)

	<u>Factor</u>	<u>P-Value</u>
Site		.22
Week		.00
Week x site		.04

Table 2.7. Soil moisture 10 cm (pole-sized plots).

	<u>Factor</u>	<u>P-Value</u>
Site		.00
Week		.00
Week x site		.01

Differences between treatments indicated that analysis for the 10 cm depth be performed for each of the stand types (plantation and pole-sized tree plots). As indicated above, site differences were significant for soil moisture at depths of 10 cm on the pole-sized tree plots. Between the weeks of May 6 and October 27 soil moisture averaged 6.6% on the control and 4.2% on the antenna pole-sized tree plots. Differences between site soil moisture at depths of 10 cm on the plantation plots were not significant.

Site-week interactions were significant for all treatment depth combinations. Differences between sites for individual weeks are given in Figures 2.29 through 2.32. Differences between sites are greatest at the plantation plots during late June and early July. The smallest significant differences which could be detected in the plantations were 4.0% to 5.0% soil moisture. Differences between sites in the pole-sized tree plots were minimal in late July and early August. Significant differences as low as 2.2% could be detected at the 10 cm depth at the pole-sized tree plots but cm differences as large as 2.9% could not be detected at the 5 cm depth.

#### Available Water

Although soil moisture content is a measurement of the amount of water on a site, the amount of available water for tree growth may be quite different than the overall amount of soil moisture. A preliminary study was initiated to determine available water on each site as well as determine if site relationships indicated with the soil moisture comparison would agree with available water comparisons.

Before a comparison could be made, factors such as rock content of the soil needed to be determined. For each site three .045 m<sup>3</sup> holes were dug to a depth of 50 cm. Percent rock was determined for each site. These values along with bulk density and percent moisture at 15 Bar for each site at a depth of 5 cm and 10 cm are given below.

**Table 2.8. Rock % by weight (50 cm), bulk density, and soil moisture content at 15 BARS for all sites at 5 and 10 cm.**

	5 cm			10 cm		
	Ground	Antenna	Control	Ground	Antenna	Control
Rock %	68	13	4	68	13	4
Bulk density	1.02	1.40	1.17	1.02	1.00	1.26
Soil MC at 15 BAR	1.9	2.4	2.7	1.9	2.4	4.0

FIGURE 2.29 CONTROL-ANTENNA SOIL MC% 5 CM (PLANT.)

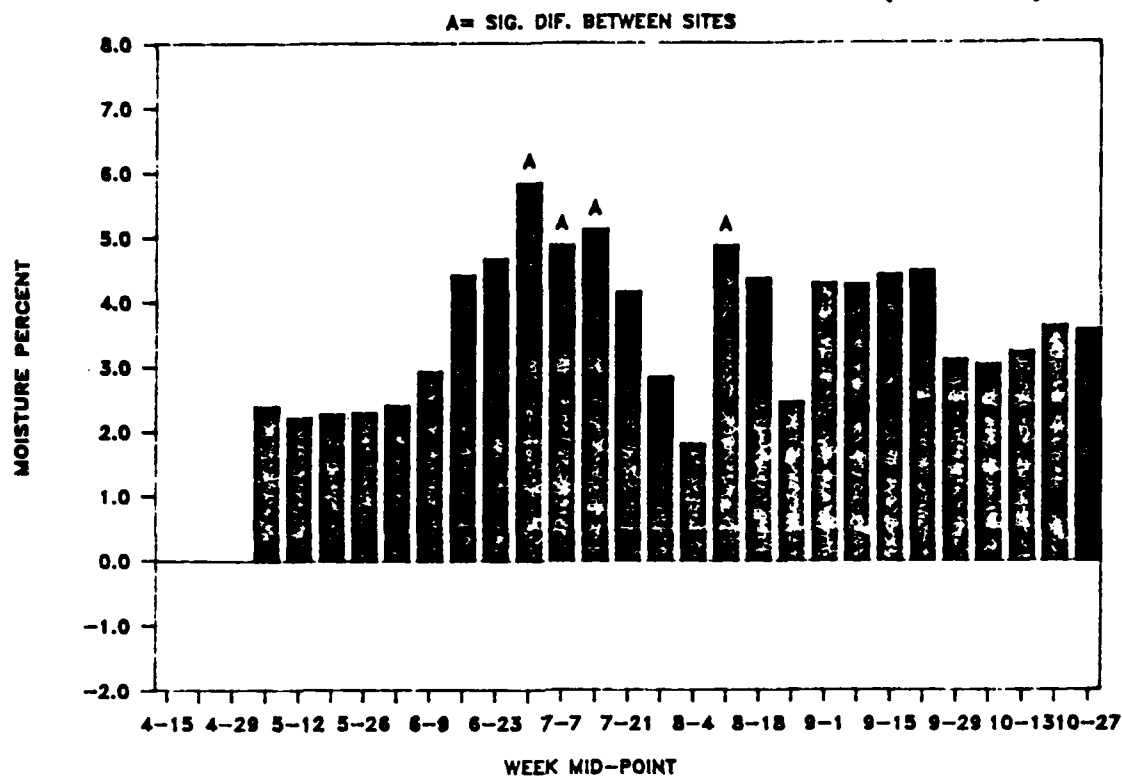


FIGURE 2.30 CONTROL-ANT. SOIL MC% 5 CM (POLE-SIZE)

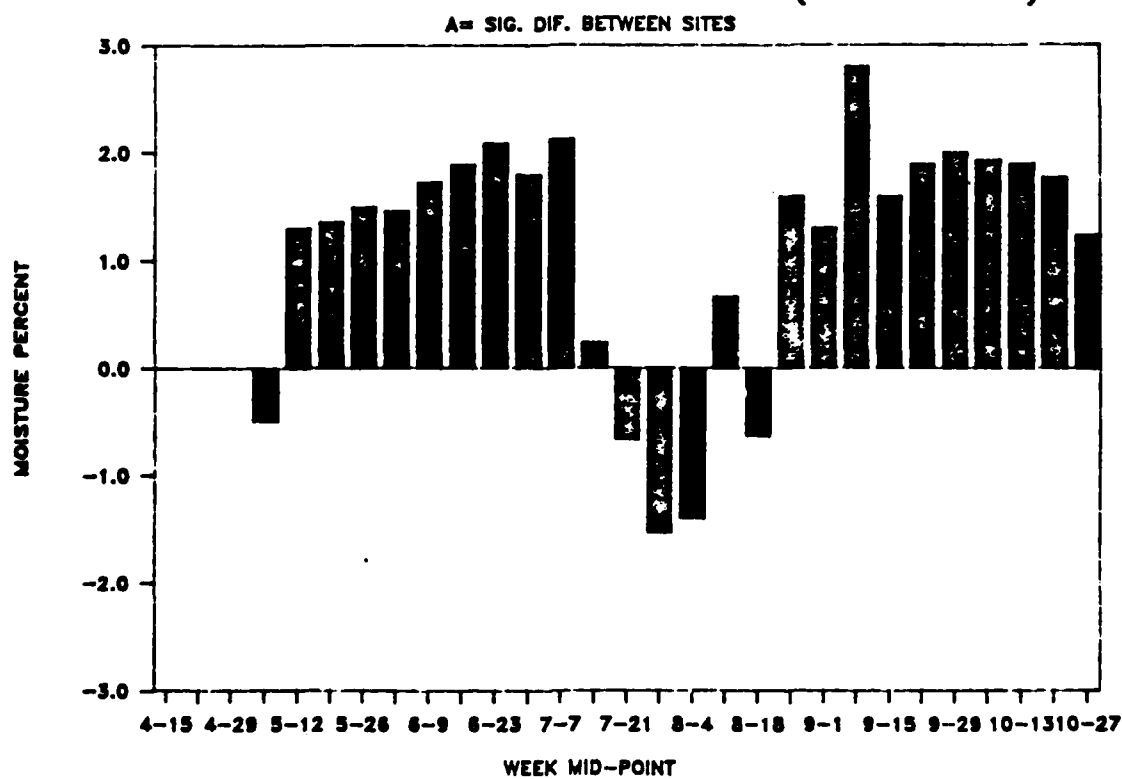


FIGURE 2.31 CONTROL-ANT. SOIL MC% 10 CM (PLANT.)

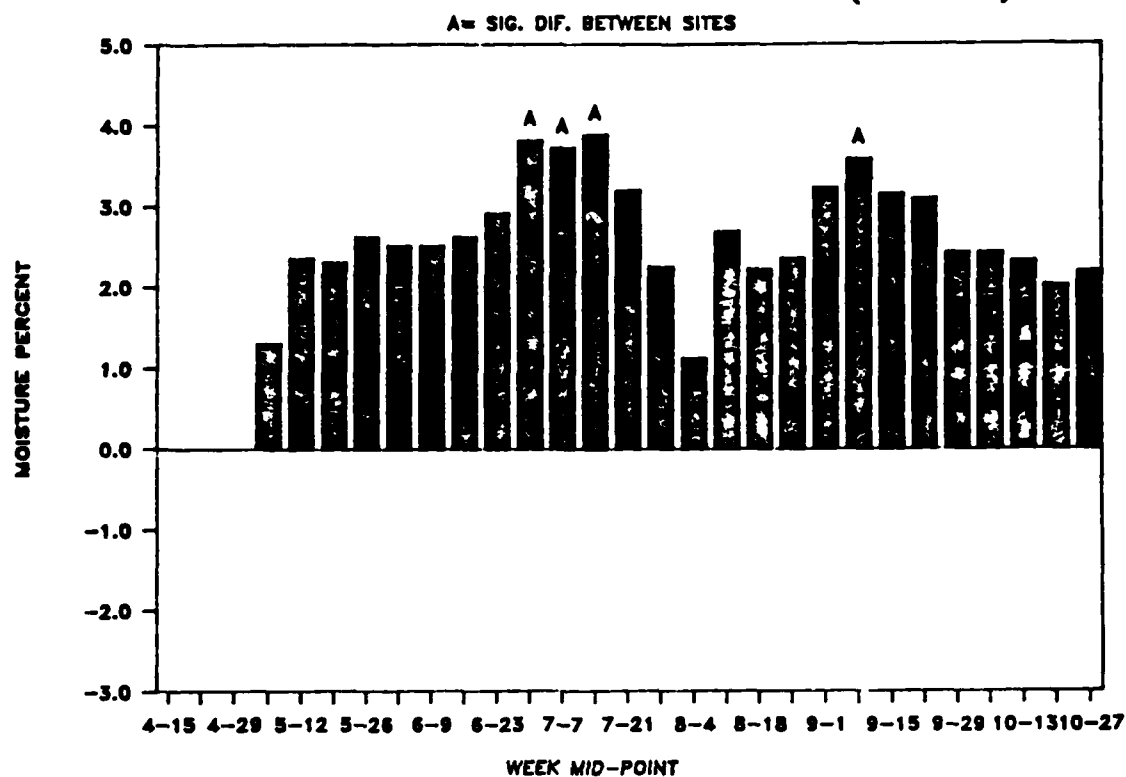
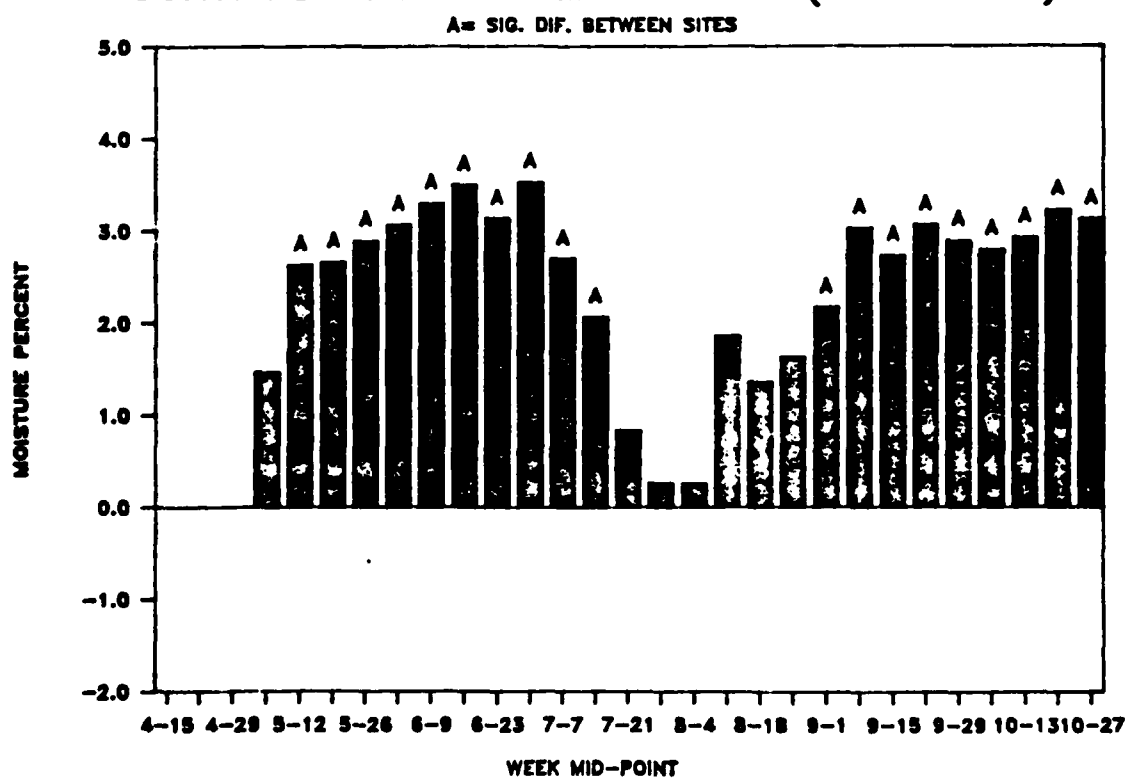


FIGURE 2.32 CONTROL-ANT. SOIL MC% 10 CM (POLE-SIZE)



The following equation was used to determine the available water for each plot for a given growing season week, at both 5 cm and 10 cm (from galvanic probes).

$$\text{cm of Available Water} = \frac{\text{Soil Moisture \% (from galvanic)} - \text{Soil Moisture \% (at 15BAR)}}{100}$$

$$\times \frac{\text{Bulk Density}}{2.65 \text{ g/cm}^3} \times \frac{1 - \% \text{ Rock (density of rock)}}{1}$$

The computed values were then used in ANOVA tests and compared to the ANOVA results from the soil moisture content comparisons. Comparisons between the control and ground sites for soil moisture percent versus available water showed that p values for site differences decrease when available water is used. At the 5 cm depth, comparisons on the basis of soil moisture were significant at  $p = 0.97$ , while comparisons were significant at the  $p = 0.29$  level for available water. Results were similar for 10 cm readings with probabilities of  $p = 0.74$  and  $p = 0.13$  for percent water and available water, respectively. Comparisons of the antenna and control sites showed that the probability levels generally increased when available water is used. These types of changes were generally due to differences in rock content.

It appears from this preliminary study that available water may be an important factor in the project. However, more intensive soil studies which will accurately determine rock content, bulk density, and moisture content at 15 BAR at each soil depth (5 and 10 cm) are needed before more accurate estimates of available water on each plot can be made.

### Precipitation

The amount of precipitation received and the distribution of precipitation over time is one of the primary factors controlling the amount and timing of the availability of water for plant growth. Thus, precipitation, like soil moisture, affects plant growth both directly and indirectly in a number of ways.

As indicated in the discussion of system configuration, precipitation sensors are located only on the plantations at each site. In order to insure that the measurement of precipitation will not be affected by possible community structural or compositional changes induced by ELF fields, vegetation around the rain gauges will be cleared annually. Although this dictates that precipitation is independent of ELF effects, precipitation recorded by these sensors is only that which is received by the canopy of the vegetation.

#### Missing Data Replacement

Missing precipitation values on the antenna and ground sites were treated in the same manner as missing air temperature values (two meters above the ground). A paired t-test was used to compare the precipitation on the ground and antenna sites for the weeks that each site had recorded all rain storm events. Differences between sites were not significant ( $p = .557$ ) and thus missing data were replaced with data from the other site.

#### Site Comparison

Figures 2.33 and 2.34 show the weekly total precipitation for all sites in the study during the growing season. The heaviest periods of rainfall occurred in late August and in September. The largest weekly total rainfall was recorded the week of September 29. Average weekly total rainfall on the ground, antenna, and control was 0.85, 0.84, and 0.73 inches respectively. Paired t-tests were performed to test differences between ground and control as well as the antenna and control sites. No significant differences ( $p = 0.25$ ) between the ground and control and between the antenna and control ( $p = 0.30$ ) average weekly totals were found.

Although t-tests give an indication of differences of average weekly totals, no specific information is gained about any differences between

FIGURE 2.33

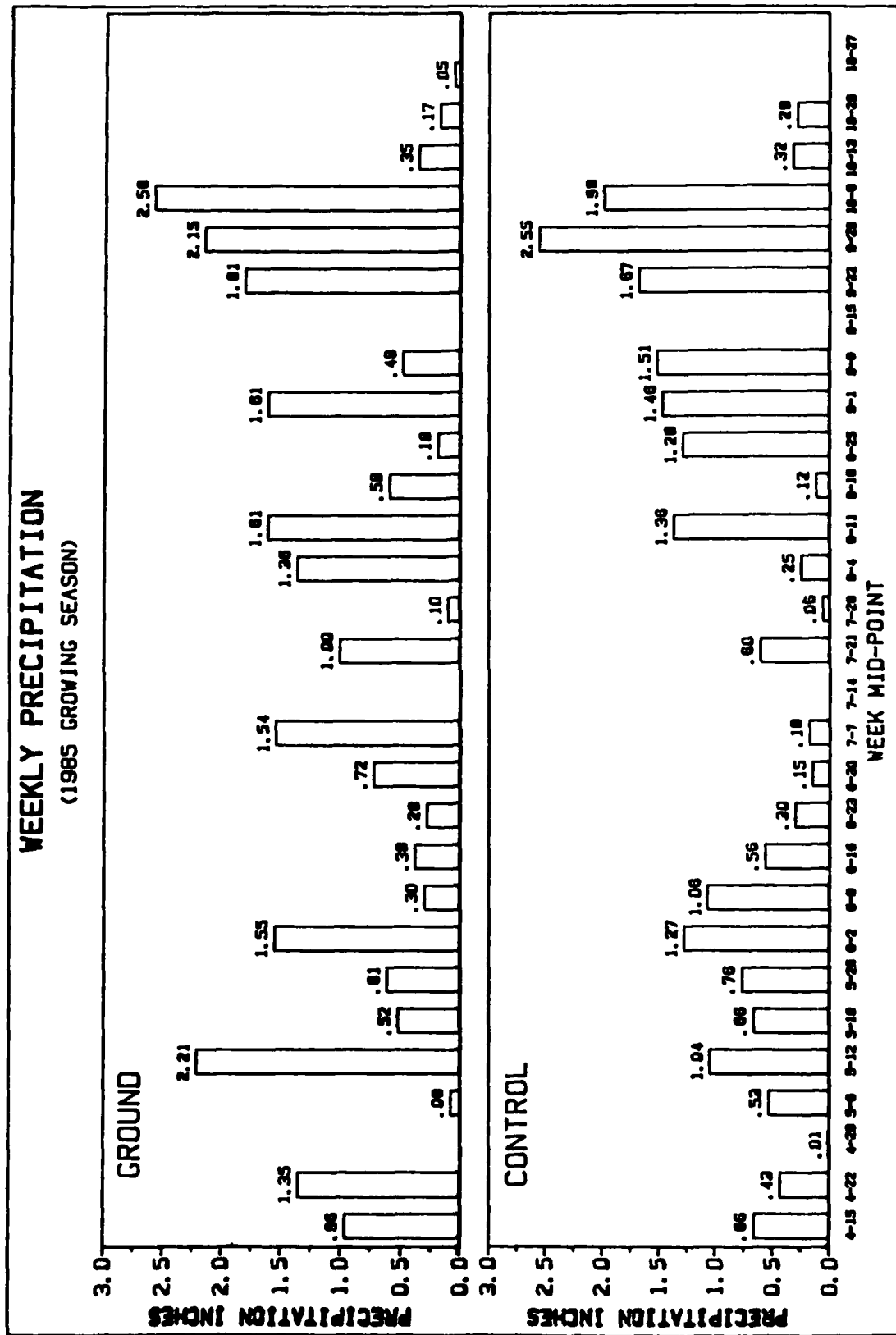
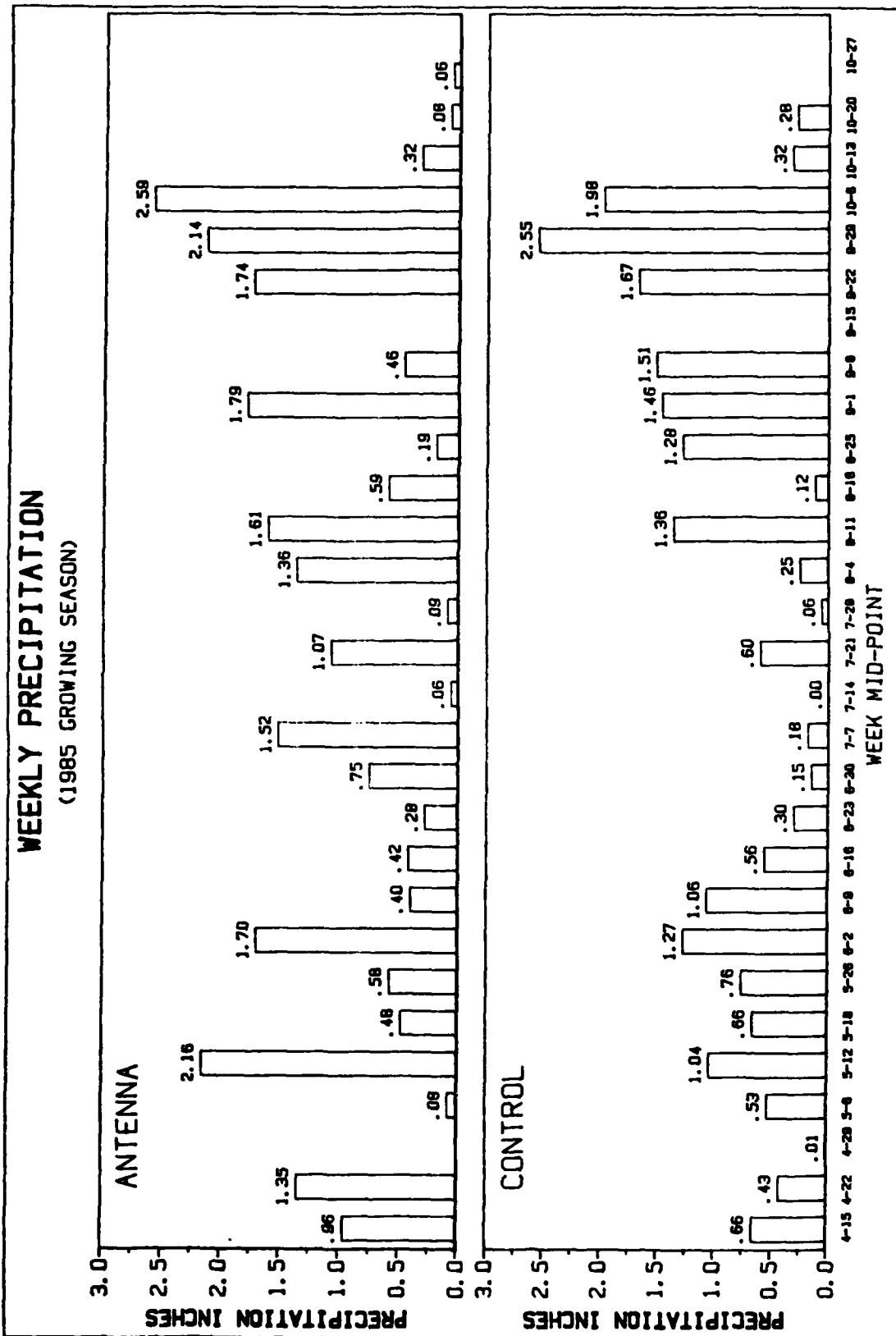


FIGURE 2.34





sites for specific periods of the growing season. To answer these questions, rainfall was totaled on a weekly basis. Total rainfall received before the growing season was also added to the April 15 week total. Figure 2.35 presents these data for each site. The difference between the running total for the control site and other two sites is least the week of June 23 and greatest the week of August 1. K-S (Kolmogorov-Smirov) tests were used to determine if the rainfall data in each running total curve is from the same distribution. If the hypothesis is rejected, there are time period differences between sites. Tests for the control and ground as well as the control and antenna gave a p-value of 0.56 for each test and the hypothesis could not be rejected.

These tests have indicated that average weekly rainfall and rainfall over any specific periods of time are not significantly different among sites, however these tests give no indication if rainfall is distributed differently within weeks. To answer this question, a running total of the number of days with precipitation greater than 0.01 inch as well as 0.10 inch was calculated for the growing season. Graphs of these observations (Figure 2.36 and 2.37) indicate that differences among sites are relatively small. The total number of days with .01 inches of precipitation at the control are relatively similar to the other sites until the end of September. Figure 2.37 shows that the number of days with .10 inch of rain on the control actually departs from the general curves of the other sites in August. Comparisons of sites using the K-S test show no significant differences between the ground and control or antenna and control (0.01 inches of rainfall,  $P = .945$ ; 0.10 inches of rainfall,  $P = .564$ ). Although the K-S test is not extremely powerful, it can be assumed that differences, if any, are minimal.

Since snow pillows were not operational this winter, no snow data could be collected. Rain from each site was collected for chemical analysis. The analysis of these samples are currently underway.

FIGURE 2.35

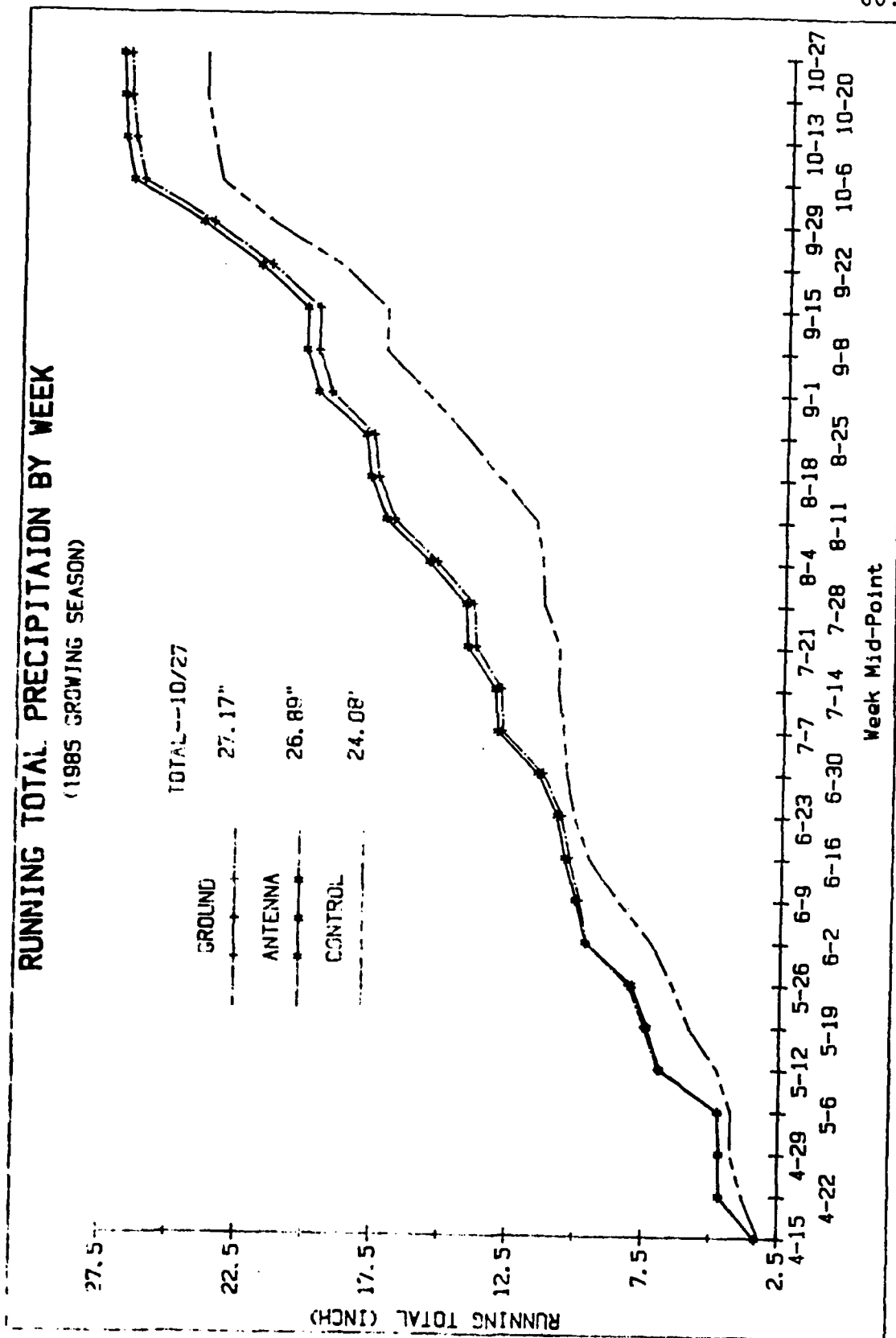


FIGURE 2.36

**RUNNING TOTAL OF DAYS  
WITH GREATER THAN OR EQUAL TO .01 INCH PRECIPITATION  
(GROWING SEASON 1985)**

61.

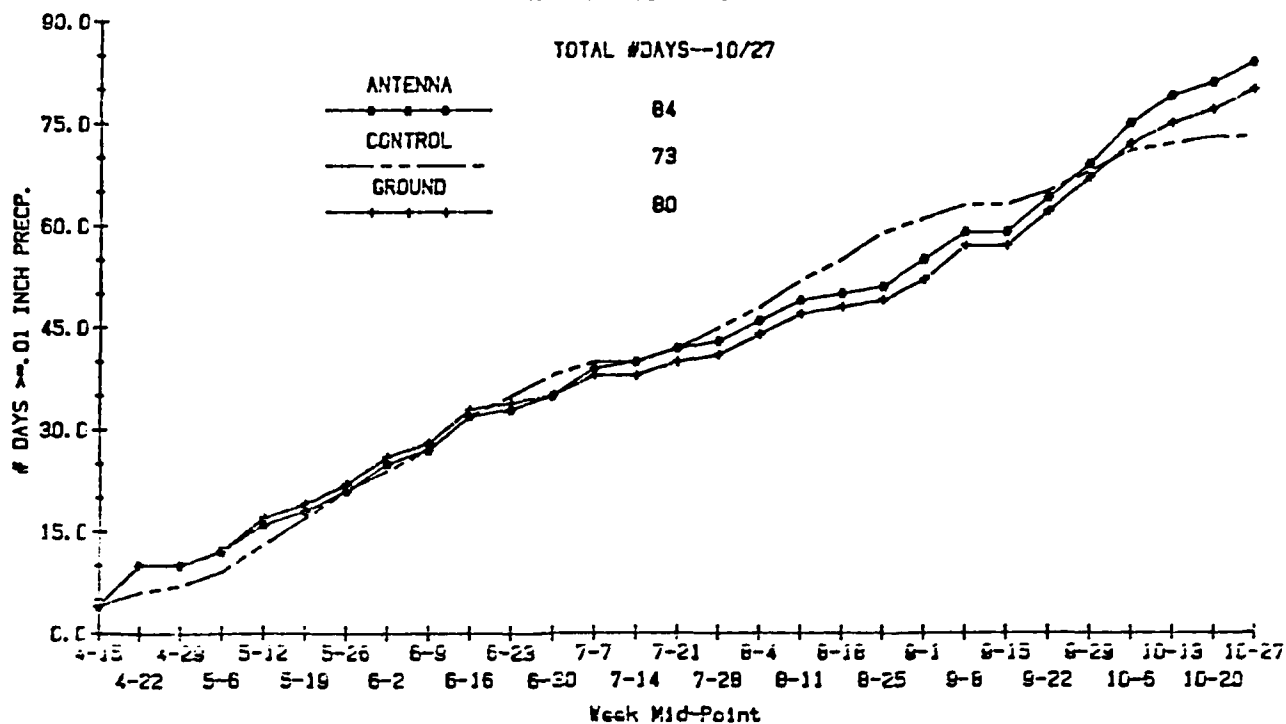
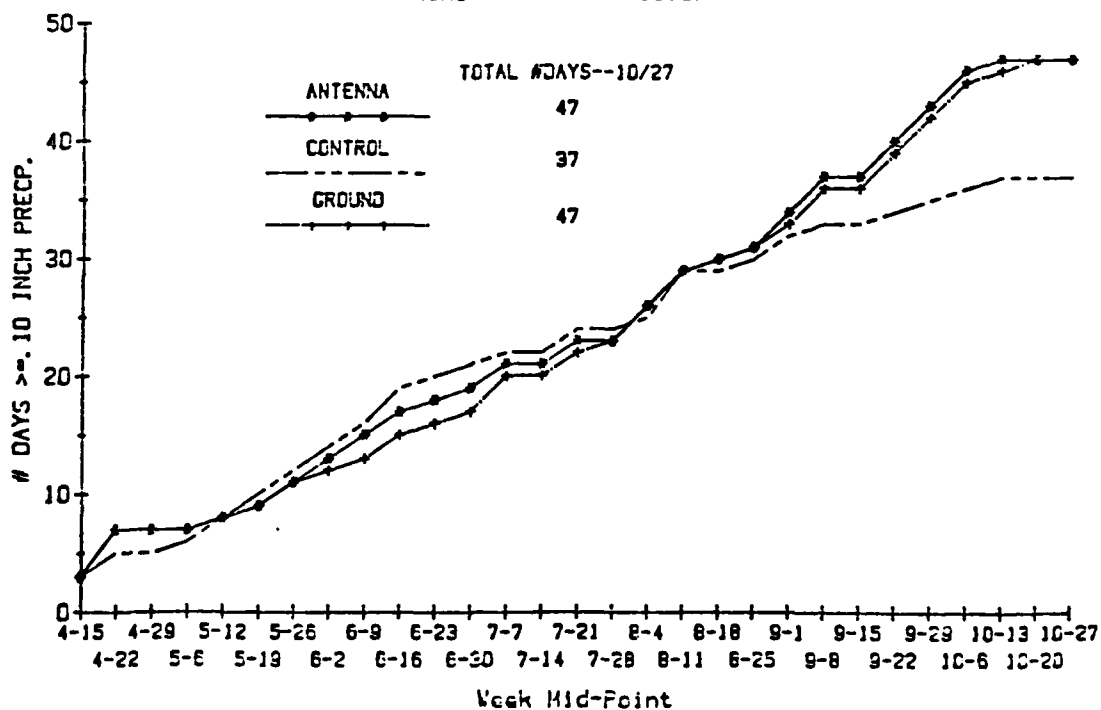


FIGURE 2.37

**RUNNING TOTAL OF DAYS  
WITH GREATER THAN OR EQUAL TO .10 INCH PRECIPITATION  
(GROWING SEASON 1985)**



### Global Solar Radiation

Solar radiation is the primary energy source for photosynthesis as well as the primary factor controlling climatic conditions. Thus the measurement of solar radiation is essential to the project.

The global radiation sensor is located 4 meters above the soil on the ground site plantation. Placement of the sensor at this height eliminates any effects of possible vegetation structural or compositional changes on the measurement of incoming solar. Thus global solar radiation measurements will be independent of ELF fields.

### Monthly Summary

Instantaneous readings of global solar radiation (300 nm to 3000 nm) were initially recorded in watts/m<sup>2</sup> and converted to langleys/minute. Table 2.9 presents the average daily global solar radiation on a monthly basis.

**Table (2.9). Average daily incoming global solar radiation (langleys/day).**

<u>Date</u>	<u>Average Daily (langleys/day)</u>
12/84	70
1/85	101
2/85	165
3/85	278
4/85	381
5/85	433
6/85	
7/85	562
8/85	
9/85	264
10/85	216

Due to repairs on the ground site platform, June and August averages could not be calculated. As one would expect, average daily radiation was lowest in December and highest (for months recorded) in July.

### Relative Humidity

Relative humidity has a pronounced effect on vegetation evapotranspiration as well as soil evaporation. Thus the relative humidity of an area or site can also effect the growth of the vegetation occupying that site. Like the air temperature sensors on the plantation plots, relative humidity sensors are located above the canopy of the red pine. As with air temperature, relative humidity is considered independent of ELF effects.

Due to repairs to the sensors, data collected from the relative humidity sensors were limited and statistical comparisons between sites could not be made. However, graphical comparison of the data indicates the differences between the control site and the other two sites may exist (Figure 2.38). Relative humidity differences between the control and antenna or ground are as much as 8 to 11 percent during the month of September. In October differences between the sites were small. Weekly average daily relative humidity from the week of June 16 to October 27 at the antenna site was 75%.

### Air Temperature (30 cm above the ground) and Photosynthetic Active Radiation

Air temperature (30 cm above the ground) and photosynthetic active radiation (300 nm - 700 nm) are being measured in the pole-sized tree plots in order to give a more accurate picture of the ambient conditions at the herbaceous reserve. These variables are considered to be nonindependent of ELF effects due to the effects of vegetation structure and distribution on air temperature and incoming solar near the ground.

### Antenna vs. Control Comparison

Figure 2.39 shows weekly average air temperature 30 cm above the ground as well as air temperature 2 meters above the ground for the antenna and

FIGURE 2.38

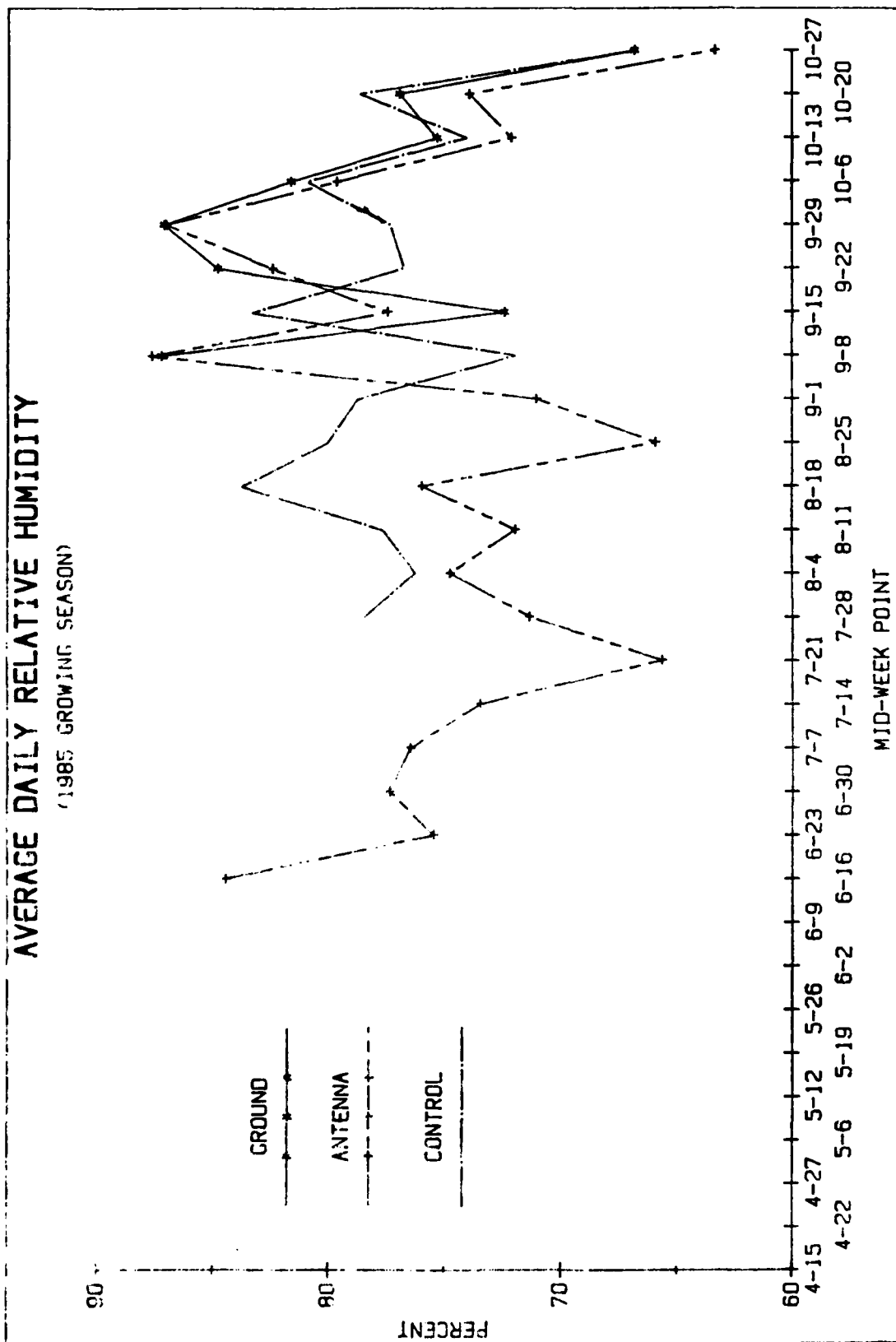
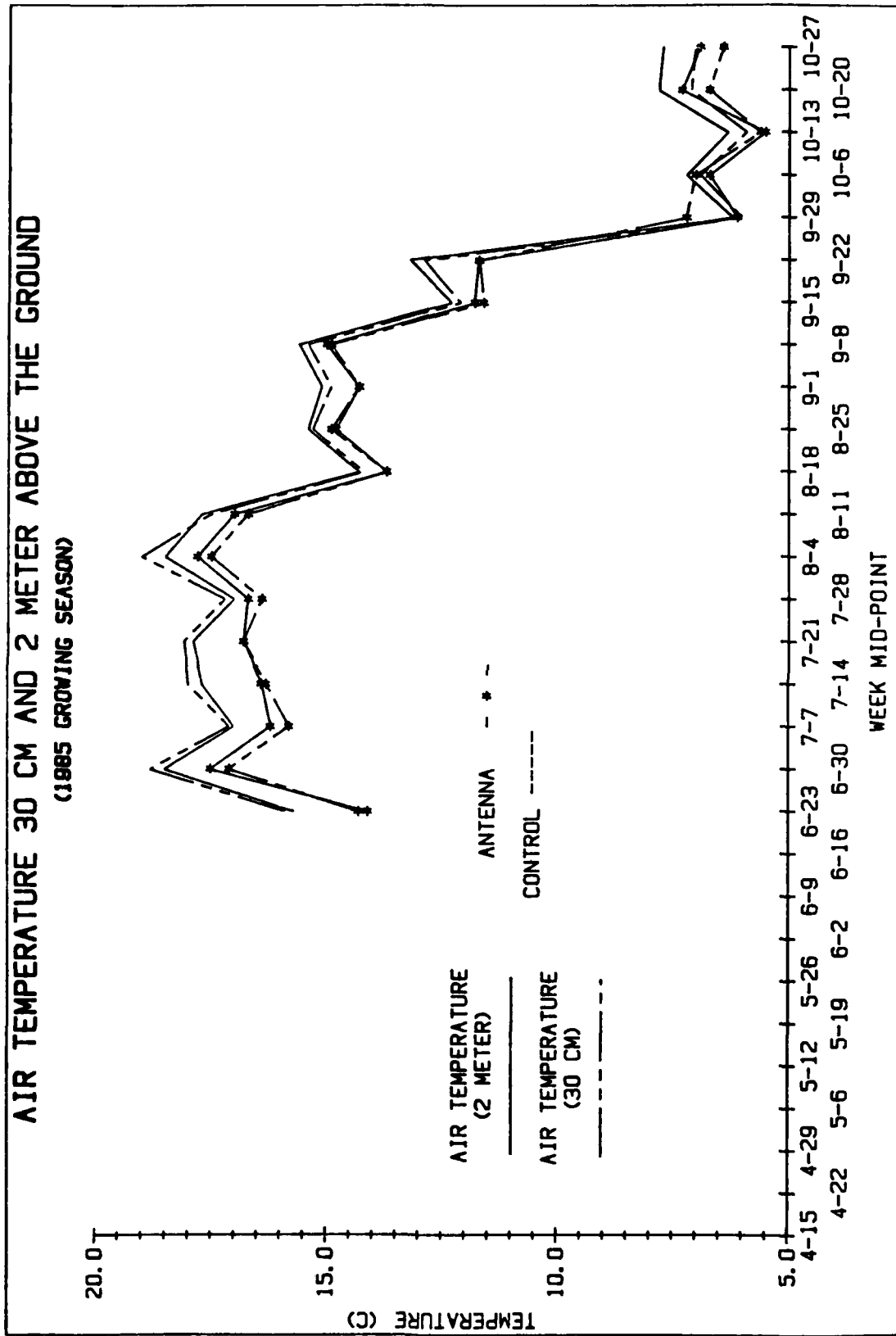


FIGURE 2.39



control sites for the week of June 16 through October 27. The relationship between the sites using air temperature at the 30 cm height is very similar to the relationship using air temperature 2 meters above the ground. The control site had consistently higher air temperatures than the antenna site no matter what height above the ground the readings were taken. Differences of air temperatures at a height of 30 cm compared to 2 meters were extremely small. Differences were greatest in late fall (September 22 to October 27) and least during the summer (June 23 to September 15).

Photosynthetic active radiation (PAR) was measured at the control and antenna pole-sized tree plots in areas with similar canopy conditions. Table 2.10 gives daily average measurements. Downtime of the sensors makes it impossible to compare the PAR between sites. Highest PAR values before leaf fall were obtained preceeding the summer solstice. During and after leaf fall (October 13 through October 20) PAR values increases 200 to 300% compared the week previous to leaf fall.

### Future Consideration

#### Soil Moisture

As mentioned previously variation in soil moisture content readings among plots is considerable. This variation may not only represent variation among plots, but variation within the plots themselves. In order to reduce measurement variation on the site and obtain an accurate estimate of the soil moisture on each plot, 15 core samples from each plot will be taken (5 cm and 10 cm) once a month. Moisture content of each core from each depth will be determined gravimetrically and an average moisture content for each depth on a plot will be calculated for that sampling day. Using these plot averages, soil moisture readings for each plot over the entire month will be adjusted according to the relationship between the



Table 2.10. Daily average PAR values per day in pole stand 30 cm above the ground (Einstein/meter<sup>2</sup>).

<u>Week</u>	<u>Antenna</u>	<u>Control</u>
6/19	3.7	2.7
6/16	3.1	2.2
6/23	2.8	2.2
6/30	3.3	1.8
7/7	*	1.5
7/14	*	2.7
7/21	*	1.9
7/28	3.7	*
8/4	2.3	1.5
8/11	*	1.6
8/18	*	1.6
8/25	2.8	*
9/1	1.2	*
9/8	1.5	*
9/15	2.5	*
9/22	1.3	*
9/29	1.6	*
10/6	1.8	*
10/13	4.4	*
10/20	5.5	*

\* Denotes sensor was being repaired.

galvanic soil moisture probe readings and the calculated plot soil moisture (determined gravimetrically) average for the day of core sampling.

#### Available Water

To further quantify the available water on a site during the growing season, soil samples will be taken from each plot at depths of 5 and 10 cm. These samples will be used to determine rock content, bulk density, and moisture content at 1/3 and 15 BAR pressure. This information will be used with moisture content measurements by the galvanic probes to determine available water on a weekly basis. These data will allow a more accurate estimation of available water on each plot as well as a more comprehensive evaluation of site differences.

#### Ambient Variable Relationships

Although not quantified this year, determination of the relationships between individual ambient variables is an important step in the accomplishment of the objectives of Element 2. The evaluation of these relations could indicate ambient variables which could be used as covariates in statistical tests comparing an individual ambient variable among sites or years. For example, differences in precipitation from one year to the next may explain differences in soil moisture content from year to year.

Determination of relationships between factors such as air temperature, global solar radiation, and soil temperature will help to determine possible ELF effects on nonindependent ambient variables. Thus, a more intensive study of the ambient variables is planned for the next year in order to more fully understand actual ecological relationships of each climatic factor.

### ELEMENT 3. TREE PRODUCTIVITY

Tree growth is sensitive to a variety of environmental disturbances. In order to detect any changes in growth due to site disturbance, accurate tree measurements are essential. The most widely accepted tree growth measurements are diameter at breast height outside bark (dbh) and height. Of these two growth variables, height is the more difficult to measure. The installation of permanent dendrometer bands on the stem of a tree allow measurement of minute changes (0.25mm) in diameter over a short time interval (Husch, et al., 1972). Two additional advantages in using dbh as a measurement of tree growth are the responsiveness of cambial activity to environmental effects (Smith, 1962) and the strong correlation existing between dbh and total biomass of the tree (Crow, 1978). Consequently, measurements of diameter increment will be the primary response variable for assessing ELF fields on stand growth. Tree height was used for initial stand characterization.

While dbh and height measurements can provide information on present stand production and a means to predict future productivity, the capacity of a stand to continue producing can be determined by monitoring tree reproduction and mortality. Stand structure (the distribution of trees by diameter classes) changes from year to year due to natural ingrowth (reproduction) and mortality of trees. Any environmental disturbances could produce an effect on these two factors. Thus, ingrowth and mortality need to be monitored and recorded in order to distinguish natural changes from those by site disturbances. Therefore, to achieve a complete picture of possible ELF effects on the tree and stand production, dbh, height, ingrowth and mortality will be measured.

In addition to tree productivity in pole-sized stands, regeneration studies involving planted red pine seedlings are being conducted on the

ground, antenna, and control sites. This study was initiated in response to a need for a more adequate number of conifers in the ectomycorrhizal studies (Element 7) as well as for the Michigan DNR concerns on forest regeneration. Since young trees often exhibit rapid growth rates, possible ELF field effects on these seedlings may be more easily detected than in older trees. Again, as in the case of trees in the pole-sized stands, dbh, height, and mortality will be measured.

### POLESIZED STANDS

Diameter increment is the primary response variable for assessing effects of ELF in the polesized stands located on the antenna and control study sites. Permanently installed dendrometer bands allow continual measurements of incremental growth on each tree in the stand. This information provides a view of both the level of growth on a given tree at a particular time and the total growth in an entire growing season. An indication of the rate or distribution of the growth over the growing season can also be derived and examined.

Polesized stands on both study sites are classified in the Acer-Quercus-Vaccinium habitat type (Coffman et al., 1983). Those species common to both sites and considered in the analysis include northern red oak (Quercus rubra), paper birch (Betula papyrifera), bigtooth aspen (Populus grandidentata), and red maple (Acer rubrum). A summary of stand information for 1985 can be found in Table 3.1.

Each analysis will eventually test the overall null hypothesis:

$H_0$ : There is no difference in the level or the pattern of seasonal diameter growth before and after the ELF antenna becomes operational.

Table 3.1 Summary of pole-sized stand information for the antenna and control sites in 1985.

SPECIES	ANTENNA					
	Average DBH (cm)	Average Total Ht. (m)	Average Basal Area (m <sup>2</sup> /ha)	Number of Stems Per Hectare	Site Index	Age (yrs)
Northern Red Oak	22.45	17.62	6.57	143	68	46
Paper Birch	20.23	19.62	0.86	25	66	54
Big Tooth Aspen	25.01	20.27	2.43	48	68	49
Red Maple	15.09	16.43	7.78	410	56	41

Species	CONTROL					
	Average DBH (cm)	Average Total Ht. (m)	Average Basal Area (m <sup>2</sup> /ha)	Number of Stems Per Hectare	Site Index	Age (yrs)
Northern Red Oak	20.55	22.24	20.00	556	72	51
Paper Birch	16.47	20.63	2.92	127	60	53
Big Tooth Aspen	22.96	23.51	3.33	79	65	54
Red Maple	11.97	16.31	0.52	48	58	44

Each year prior to a fully operational system, a baseline of each stand's structure and the relationship between the two sites will be established through tests of the following hypothesis:

$H_0$ : There is no difference in the level or the pattern of seasonal diameter growth between the antenna and control sites within a year.

Tests of rate or distribution of diameter growth are made using the nonparametric (two-sample) Kolmogorov-Smirnov test at the  $\alpha = .05$  level. Differences in level or amount of seasonal diameter increment are detected through analysis of the split plot in space and time design. Assuming the covariate changes over time, the ANOVA table used in this study is found in Table 3.2. If the covariate does not change over time, the second covariate term in the ANOVA table drops out and the degrees of freedom for the Error (SY) increases by the number of covariates.

#### Sampling and Data Collection

Permanent dendrometer bands were installed in 1984 at dbh on all trees greater than or equal to 10 cm to monitor diameter growth at both study sites. Due to vandalism, 175 new bands had to be constructed and installed on the control site. By mid-April all of these bands had been replaced incorporating procedures developed by Liming (1957) and revised by Cattellino et al. (1985). In addition, code numbers were hidden on all trees and plots were mapped as discussed later in the section. On the antenna site the number of study trees was reduced from 209 in 1984 to 197 in 1985 due to a few band failures and a small vandalism incident unrelated to that on the control site. The death of one bigtooth aspen on the control site reduced that sample to 274 trees.

Table 3.2. ANOVA table used for analysis of diameter growth by species and by diameter class.

<u>Source of Variation</u>	<u>df</u>	<u>SS</u>	<u>MS</u>	<u>F</u>
Covariate	#covariates			
Site	1	SS <sub>S</sub>	MS <sub>S</sub>	MS <sub>S</sub> /MSE(S)
Error(S)	#trees-2-#covariates	SSE(S)	MSE(S)	
Years	#years-1			
Site X Years	(1)(#years-1)	SS <sub>Y</sub>	MS <sub>Y</sub>	MS <sub>Y</sub> /MSE(SY)
Covariate	#covariates	SS <sub>SY</sub>	MS <sub>SY</sub>	MS <sub>SY</sub> /MSE(SY)
Error(SY)	(# trees-2-#covariates)(#yrs-1)	SSE(SY)	MSE(SY)	

Bands were read to the nearest .01 inches of circumference at both study sites beginning on May 1 in an attempt to insure monitoring of diameter growth initiation. Weekly readings continued until October 10 when growth had slowed considerably (at least 95% of total incremental growth had occurred) and over 50% of leaf fall had taken place. This provided a total of 24 measurement periods during the 1985 growing season.

Other variables which were collected on a regular basis for both study sites included tree diameter and height. These seasonal measurements were collected in a continued effort to update the status of the study sites through time. A monthly collection of 20 soil samples per plot was also conducted on both study sites using a soil probe inserted to a depth of 15 cm. These samples were composited to 5 per plot and will be analyzed for nutrient content by plot. Each nutrient will then be tested as an independent variable in the regression analysis of diameter growth as described later in this section.

In an effort to obtain more accurate growth measurements from dendrometer band readings, a support study was initiated to determine the amount of slack which would be taken up as the tree "grows into" a newly installed band. Correction of slack in those bands installed in 1984 was done with a regression model developed by Auchmoody (1976) for black cherry (Prunus serotina). Adopting methodology similar to Auchmoody's, development of regression equations specific to the study sites and species was accomplished. A sample of six to ten study trees was chosen from each site and for each species type. Trees were sampled if it was felt that they had adequately taken up the band slack. These trees were then fitted with a second dendrometer band using the same methodology as the initial band and read weekly at the same time as the original band. At the end of the growing season comparisons were made of the growth as recorded on the new



band to the actual growth recorded on the original band where all slack had been taken up. Using simple linear regression methods, a relationship between true circumference growth and circumference growth taken from a new band was developed as is shown in the equations in Table 3.3.

**Table 3.3. Equations developed for x/y relationships where x is actual circumference growth and y is new band circumference growth for study trees on both the antenna and control sites.**

SPECIES	SAMPLE SIZE	$X = b_0 + b_1 Y^*$		R <sup>2</sup>	STANDARD ERROR
		$b_0$	$b_1$		
All trees	71	0.106	0.902	83.0	.069
Northern Red Oak	18	0.088	1.030	85.6	.069
Paper Birch	12	0.095	0.906	57.3	.078
Red Maple	16	0.148	0.575	35.5	.050
Quaking Aspen	25	0.104	0.901	87.5	.072

\*x and y are both in inches of circumference.

These equations are then applied to those study trees at the control site with newly installed bands to adjust seasonal circumference growth. As in last year's adjustment, a point of slack retention was subjectively picked from the weekly readings and the full adjustment applied to every reading thereafter. Linear growth was assumed from the point of the first band reading to that point of slack retention. If the study tree did not show what was considered adequate growth (.05 inches of circumference), the correction factor was not applied. This prevented any overestimation of growth and subsequent "negative" growth from one study year to the next.

Another support study initiated in 1985 involved the mapping of all trees on both study sites. Locating each tree's position on the plot was done using a plot coordinate system. The coordinate system was developed on the plot with two loggers tapes which crossed at plot center. Each tree could then be located by the use of a right angle prism along each tape

line. Looking through the right angle prism, the tree could then be lined up perpendicular to each tape line and the prisms' locations along those tapes would be the respective coordinates. After the information was collected for both sites, a computer program was developed to physically produce a map for each plot as shown in Appendix C.

The tree position information will be useful in the future to insure the replacement of dendrometer bands on study trees in the event of band failure or acts of vandalism. Precisely measuring the position of each study tree on the plot may also be used along with crown competition factor to quantify the effects of tree competition on the sites.

The mapping information will also be useful in evaluating the performance of diameter growth models developed during this study. Using procedures developed by Reed and Burkhardt (1985), differences between predicted and actual growth rates will be evaluated to determine if they are spatially correlated (i.e., do neighboring trees tend to be over- or under-predicted simultaneously). If errors in prediction of diameter growth are spatially correlated, then additional information on intertree competition will need to be incorporated in the diameter growth model. If there are no spatial relationships detected for growth model error, then intertree competition will be adequately accounted for in the growth model.

## Progress

### Growth Analysis

Levels and rates of diameter increment were examined for each species. Varying growth rates among species requires separate analyses for each tree species. Each of the four species is also separated into 5 cm diameter classes and those present within a diameter class on both sites are compared. Five diameter classes are presently identified and include trees

with diameters of 10.0 cm to 14.9 cm, 15.0 cm to 19.9 cm, 20.0 cm to 24.9 cm, 25.0 cm to 29.9 cm, and 30.0 cm to 34.9 cm.

Analysis of tree diameter increment is approached in two ways. Analysis of the split plot design in space and time coupled with significant covariates will be used to determine if there is any change in the level of average yearly diameter growth due to operational ELF fields. Secondly, regression models developed from weekly incremental readings will be tested for changes in diameter increment due to ELF effects during a year. Though an overall average yearly diameter growth may not change due to operational ELF fields, the rates of growth within a year and the relationship with site and climatological variables may vary and could be detected. Both analyses will incorporate tree, site, and climatological information.

#### Analysis of Total Seasonal Diameter Growth

At present, two years (1984 and 1985 field seasons) of diameter increment data have been collected from trees on the study sites. In 1984, however, first incremental growth was not recorded until early June due to a relocation of the control site. Thus, comparisons of total diameter increment between the two study sites in 1984 and 1985 were restricted to those weeks following June 10. Preliminary analyses were made with dbh, total height, or basal area as well as transformations of these variables as covariates. None of these covariates proved significant in adding additional information to the analyses. Thus, all reported analyses at this time are without covariates (see Table 3.4). Alternative covariates for future consideration are discussed throughout this section.

Table 3.4. Average seasonal diameter growth by 5 cm diameter class for tree species on each site for 1984 and 1985.

	Antenna		Control	
	1984	1985	1984	1985
Northern Red Oak				
10-14.9 cm	.116 <sup>A</sup> 1/	.124 <sup>A</sup>	.058 <sup>B</sup>	.031 <sup>B</sup>
15-19.9 cm	.205 <sup>E</sup>	.145 <sup>F</sup>	.092 <sup>G</sup>	.059 <sup>G</sup>
20-24.9 cm	.211 <sup>K</sup>	.148 <sup>L</sup>	.173 <sup>M</sup>	.143 <sup>L</sup>
25-29.9 cm	.209 <sup>S</sup>	.144 <sup>T</sup>	.190 <sup>S</sup>	.193 <sup>S</sup>
30-34.9 cm	.296 <sup>X</sup>	.214 <sup>Y</sup>	.218 <sup>Y</sup>	.255 <sup>XY</sup>
Paper Birch				
10-14.9 cm	.198 <sup>A</sup>	.194 <sup>A</sup>	.075 <sup>B</sup>	.026 <sup>B</sup>
15-19.9 cm	.041 <sup>E</sup>	.078 <sup>E</sup>	.091 <sup>E</sup>	.052 <sup>E</sup>
20-24.9 cm	.142 <sup>K</sup>	.170 <sup>K</sup>	.126 <sup>K</sup>	.101 <sup>K</sup>
25-29.9 cm	.245 <sup>ST</sup>	.299 <sup>S</sup>	.070 <sup>T</sup>	.140 <sup>ST</sup>
Pig Tooth Aspen				
20-24.9 cm	.370 <sup>A</sup>	.345 <sup>B</sup>	.307 <sup>CB</sup>	.252 <sup>C</sup>
25-29.9 cm	.403 <sup>E</sup>	.320 <sup>F</sup>	.349 <sup>F</sup>	.322 <sup>F</sup>
Red Maple				
10-14.9 cm	.092 <sup>A</sup>	.077 <sup>A</sup>	.184 <sup>B</sup>	.168 <sup>B</sup>

1/Values in rows denoted by different letters are significantly different at  $\alpha = .05$ .

Northern red oak trees are in each of the five diameter classes on both study sites. Significant site differences appeared in the 10.0-14.9 cm and 15.0-19.9 cm diameter classes (p-values of .019 and .001, respectively). Average diameter increment was consistently greater on the antenna site in comparison to the control site in both 1984 and 1985. Examination of average dbh within these diameter classes indicates little difference (13.00 cm versus 13.02 cm and 17.76 cm versus 17.57 cm, respectively). What does differ is the crown position of the trees in the stand. Those trees on the antenna site are higher in the canopy, generally co-dominant to intermediate for the 10.0-14.9 cm diameter class and dominant to co-dominant for the 15.0-19.9 cm diameter class. On the control site, trees in the 10.0-14.9 cm diameter class are in the intermediate to suppressed crown classes and those in the 15.0-19.9 cm diameter class are in the co-dominant to intermediate crown classes. Crown position appears to be one possible covariate that needs to be examined as well as previous year's diameter growth and number of stems per hectare. The control site has more stems per hectare than the antenna, and competition may vary which could explain some site variation.

In the 20.0-24.9 cm diameter class there is a significant difference in diameter incremental growth between 1984 and 1985 across both sites (p-value of .000). Growth in 1985 was consistently less than in 1984 on each site. Ambient information for 1984 is incomplete, but possible factors, such as air temperature, number of degree days above 4.4°C, precipitation, soil moisture, and soil temperature, need to be examined as covariates for these yearly differences. Growth initiation and termination appeared highly correlated with air temperature in the spring and soil temperature in the late summer. Soil moisture also seemed highly correlated to diameter growth termination (see Element 4 - Phenophase Description and Documentation).

There are few stand differences (average dbh, total height and crown position) for the 20.0-24.9 cm classes. The two larger diameter classes, 25.0-29.9 cm and 30.0-34.9 cm, had no discernable pattern in incremental growth across the sites or across the years examined.

Paper birch trees are divided into four diameter classes; no trees in the 30.0-35.9 cm diameter class existed on either study site. Significant site differences were found only in the 10.0-14.9 cm diameter class (p-value of .000) with total diameter increment again consistently higher on trees on the antenna site in comparison to those on the control site. Average dbh within this diameter class was somewhat larger on the antenna site (13.98 cm compared to 12.46 cm) as was crown position. Crown position and previous incremental growth and/or stems per hectare will be examined as covariates to possibly explain some of the existing site differences together with those ambient variables that prove significant. There was no significant difference between sites (p-values of .70 and .46, respectively) or between years (p-values of .98 and .98, respectively) in the 25.0-29.9 cm diameter class, but no apparent pattern in growth differences is discernable.

Bigtooth aspen had only two diameter classes present on each site: 20.0-24.9 cm and 25.0-29.9 cm. Both analyses showed significant differences in diameter growth in 1984 compared to 1985 (p-values of .04 and .004, respectively). Each diameter class had considerably greater growth on the antenna site in 1984 than in 1985 on either site. Stand factors such as average dbh and crown position were quite similar. Ambient variables for that time period are unavailable, thus future measurements and analysis are required for a clearer picture of the external factors involved.

One diameter class, 10.0-14.9 cm, was all that could be compared for red maple between the antenna and control sites. There were significant site differences (p-value of .0001) with consistently higher average

diameter increment on the control site compared to the antenna site. This was the reverse of all other cases of site differences. This could be the result of clustering; red maple on the antenna are generally clustered together, while on the control clustering is less evident (see plot maps in Appendix C). Differences in crown position may also be a contributing factor and need to be examined as well as ambient variables, such as air temperature, number of degree days above 4.4°C, and precipitation.

#### Analysis of Diameter Growth Rates

Regression models to test for differences in rate of diameter growth have not been developed at this time. To test for differences in the rate or the distribution of cumulative diameter increment in 1985, the nonparametric two-sample Kolomogorov-Smirnov test was employed. Diameter band data for 1984 has yet to be readjusted for slack retention and, thus is unavailable for comparison with 1985 at this time. Tests were made to detect differences in the cumulative distribution of diameter growth between the two sites for each diameter class within a species and no significant difference ( $\alpha=.05$ ) was found. These tests, however, are not very powerful and regression analysis with comparisons of estimated coefficients will provide a supporting test. Figures 3.1 and 3.2 illustrate the five diameter classes of northern and red oak on the antenna and control sites and the similar distribution of diameter increment throughout the 1985 growing season.

Despite no significant difference in the distribution of cumulative diameter increment on the two sites, some consistent patterns are evident. Regardless of the species or the diameter class within a given species, trees on the control site start growing sooner, putting on 25%, 50% and 75% of their total seasonal growth approximately 2 weeks earlier than comparable trees on the antenna site (see Figures 3.3 through 3.6). However, by the

# NORTHERN RED OAK - ANTENNA CUMULATIVE DIAMETER GROWTH - 1985

FIGURE 3.1

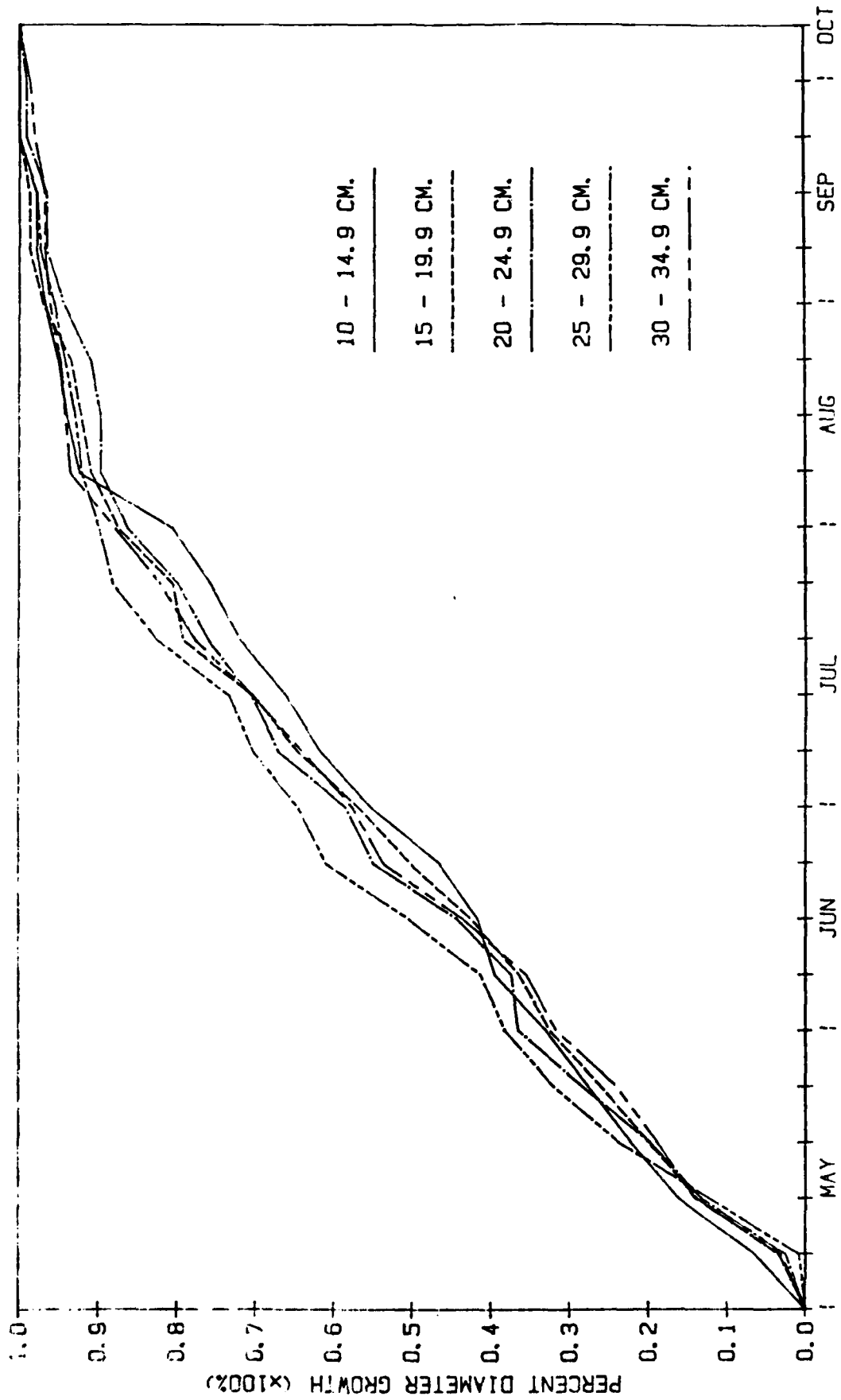
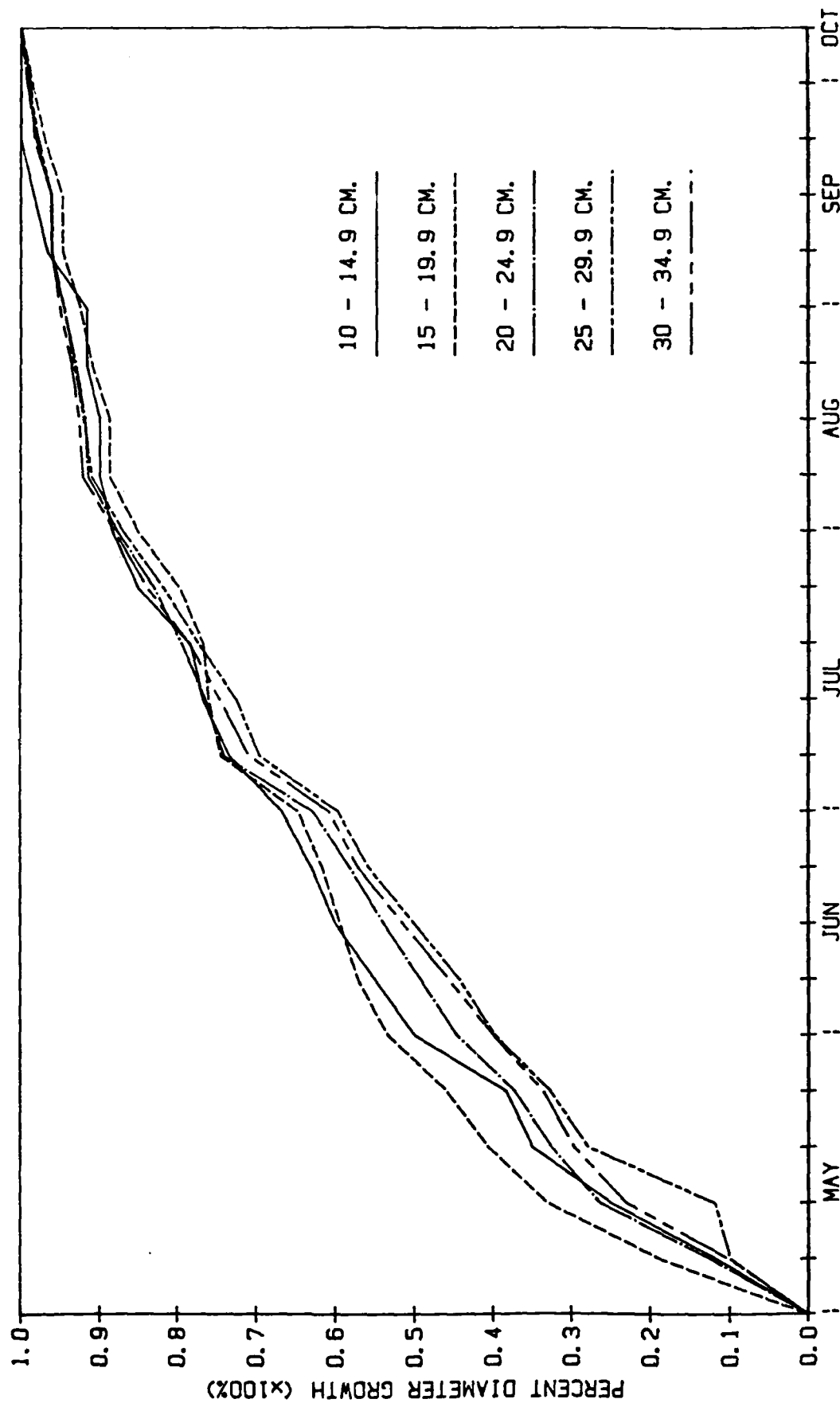




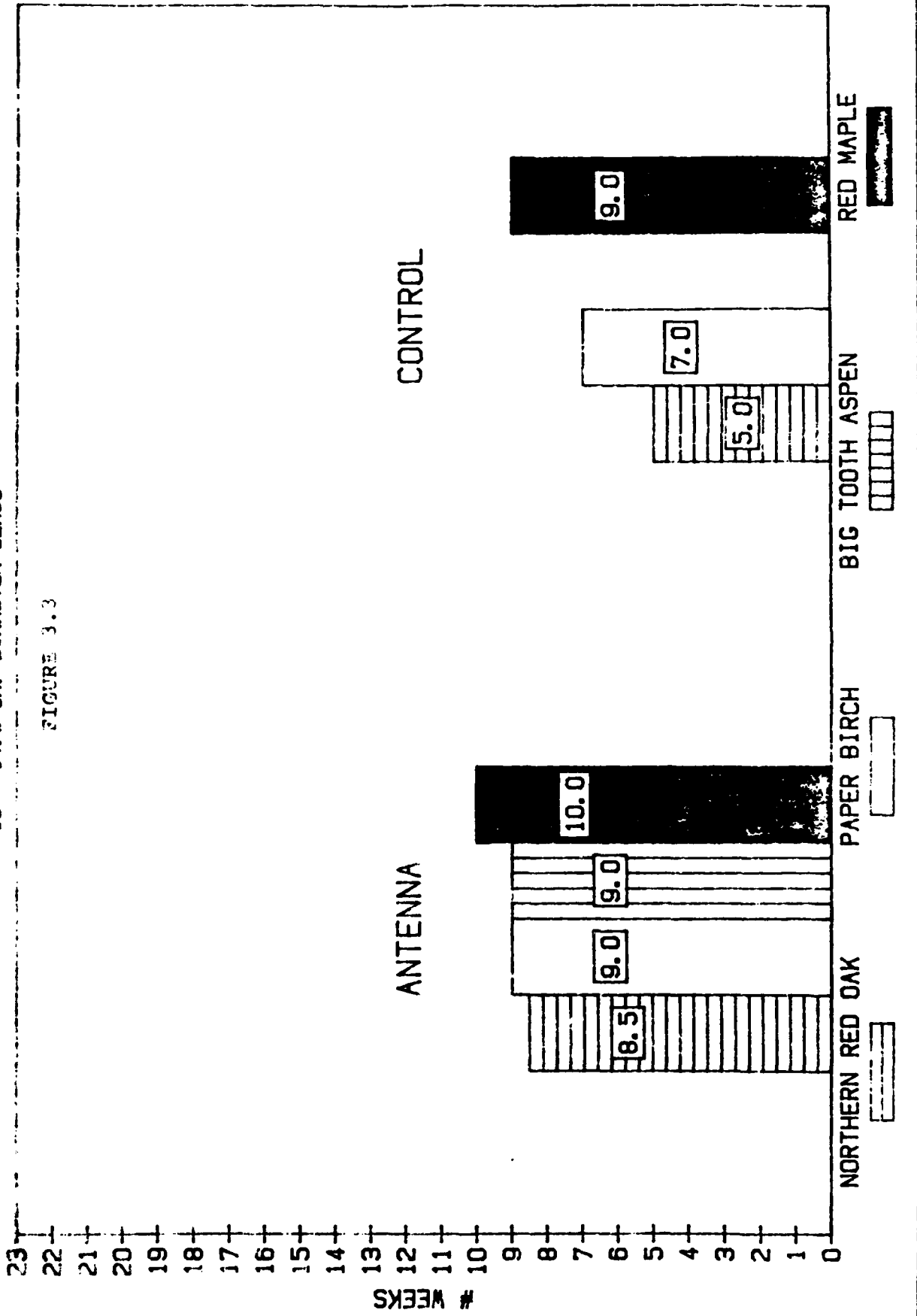
FIGURE 3.2  
NORTHERN RED OAK - CONTROL  
CUMULATIVE DIAMETER GROWTH - 1985



# NUMBER OF WEEKS TO ACHIEVE 50% OF TOTAL DIAMETER GROWTH

10 - 14.9 CM. DIAMETER CLASS

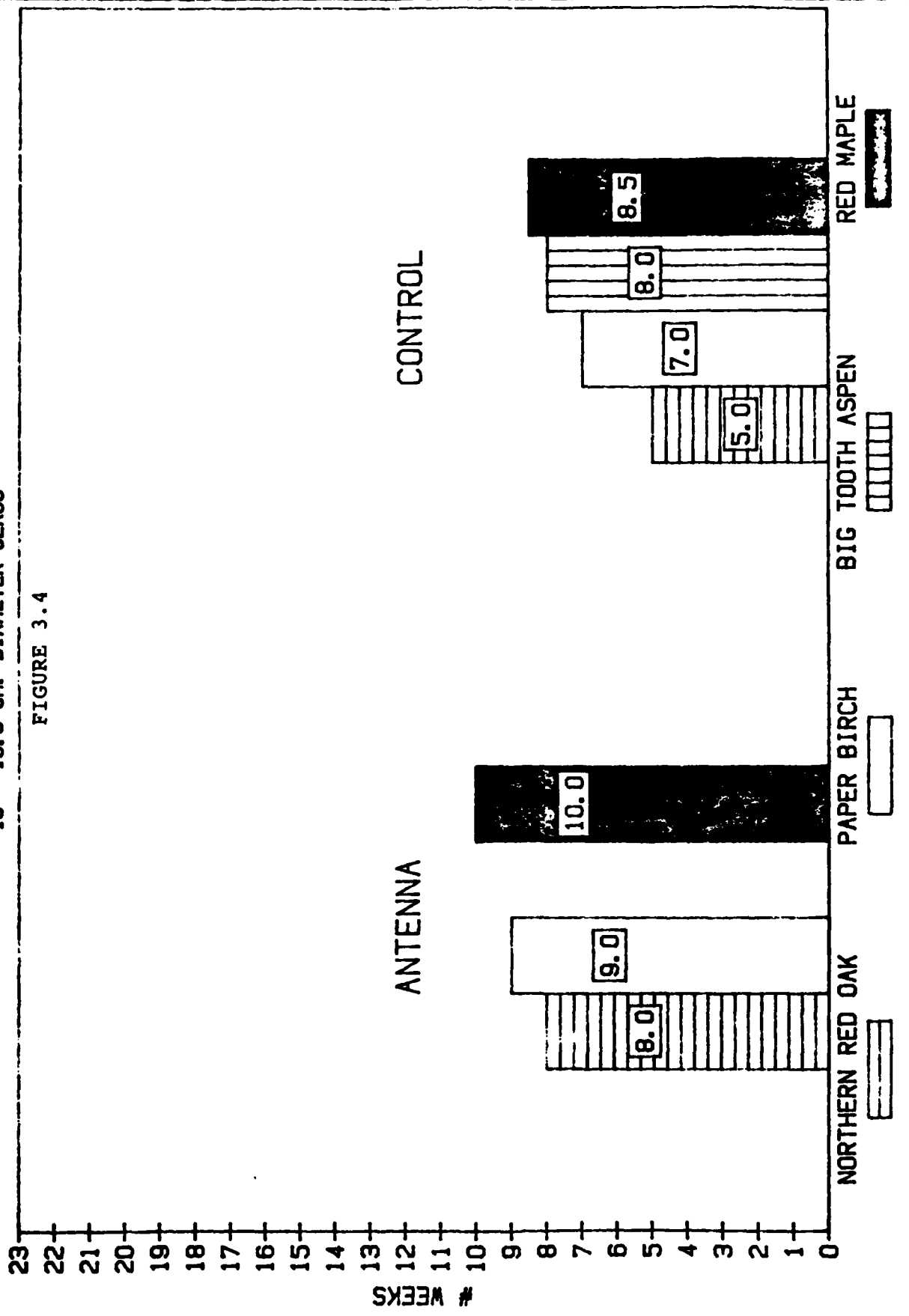
FIGURE 3.3



# NUMBER OF WEEKS TO ACHIEVE 50% OF TOTAL DIAMETER GROWTH

15 - 19.9 CM. DIAMETER CLASS

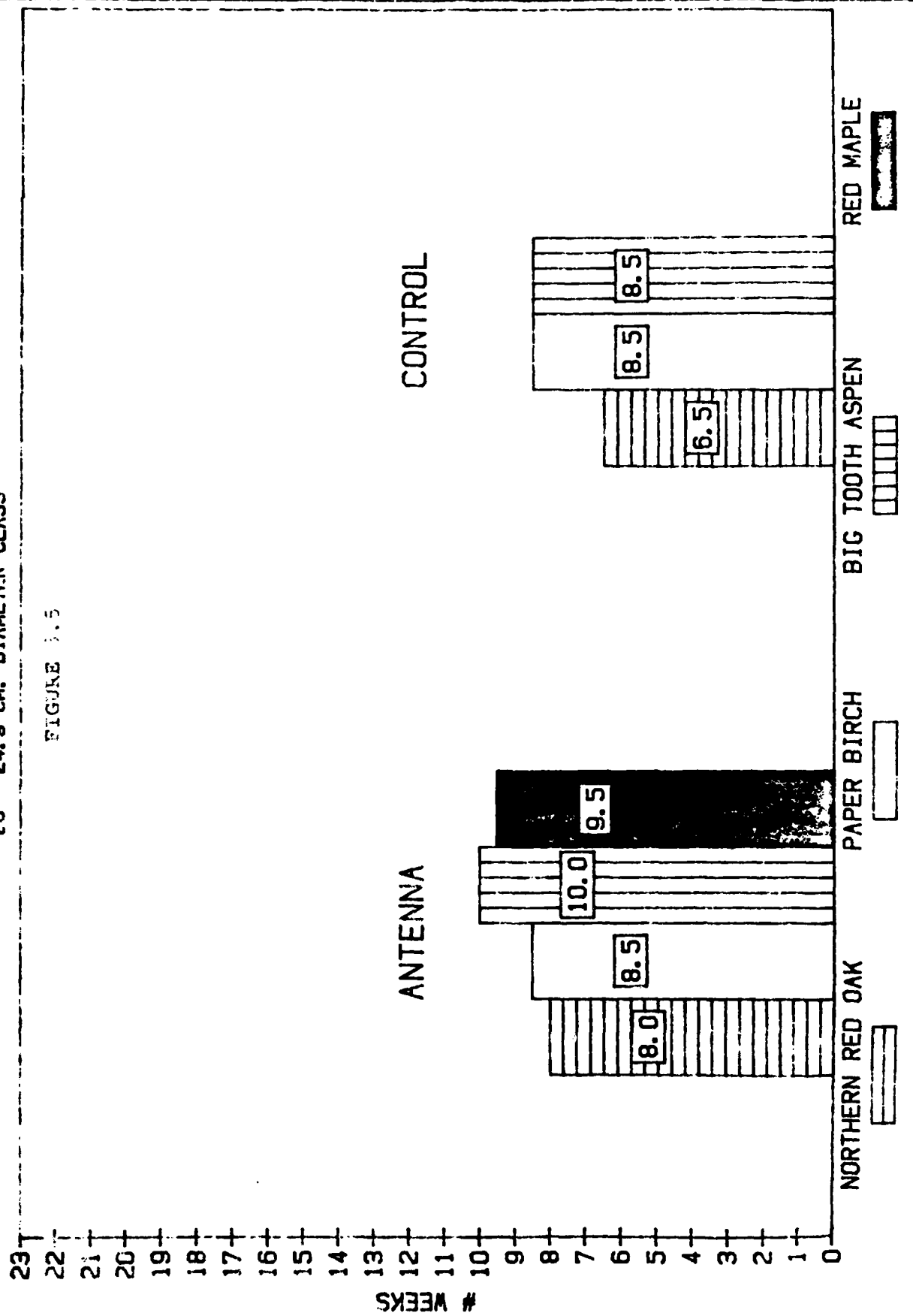
FIGURE 3.4



# NUMBER OF WEEKS TO ACHIEVE 50% OF TOTAL DIAMETER GROWTH

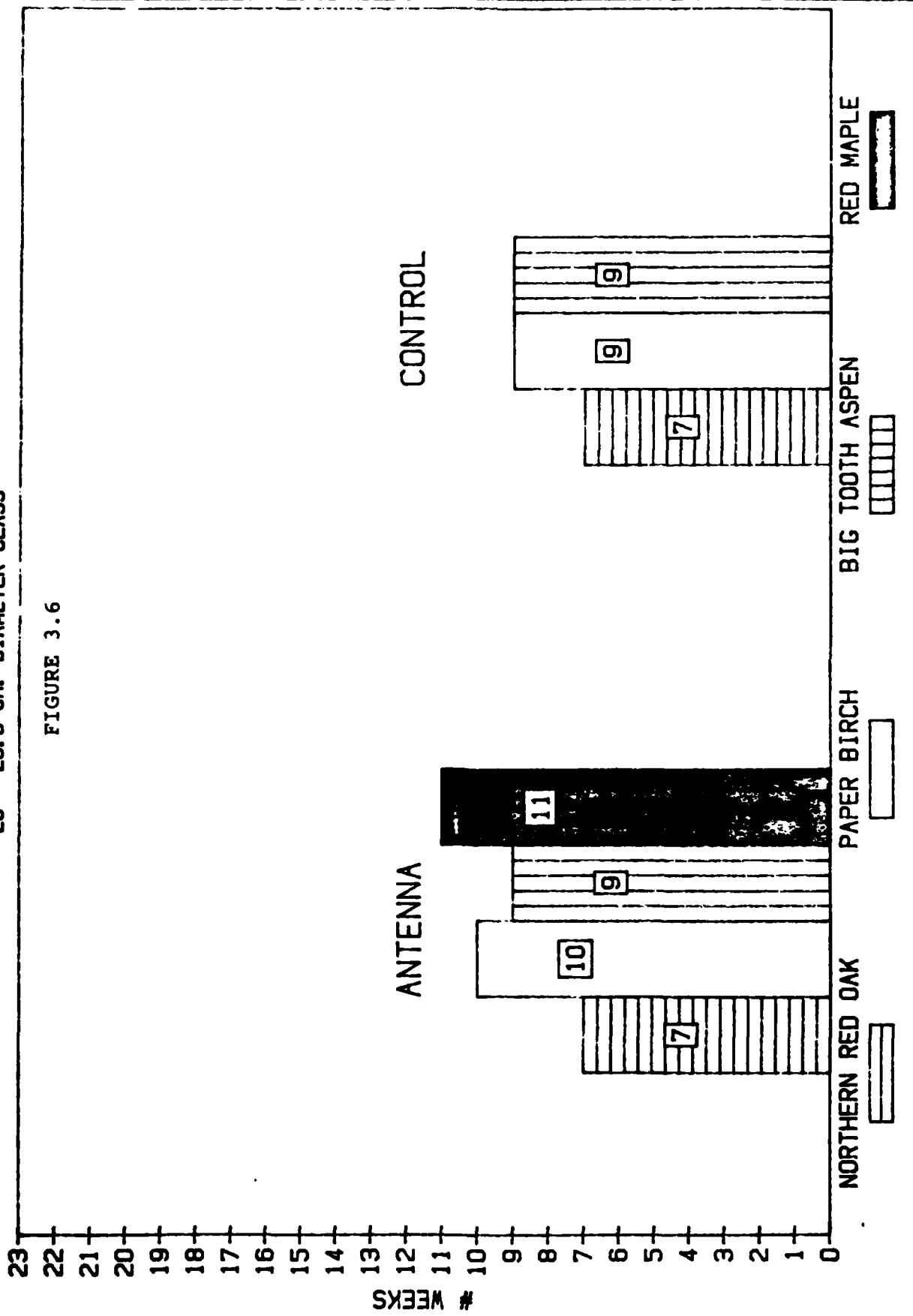
20 - 24.9 CM. DIAMETER CLASS

FIGURE 1.5



# NUMBER OF WEEKS TO ACHIEVE 50% OF TOTAL DIAMETER GROWTH 25 - 29.9 CM. DIAMETER CLASS

FIGURE 3.6



time trees on the control site have accumulated 90% of the total diameter growth for the season (around mid August), the trees on the antenna have done the same. Therefore, even though trees on the control site accumulate their seasonal growth more quickly, because of the shortness of the growing season and the quick completion of incremental growth, the trees on both sites must complete their total seasonal growth by approximately the same time. Site factors possibly contributing to this phenomenon could be warmer air temperature, moister soil conditions, and more stems per hectare. The termination of diameter growth coincides with a sharp decrease in air and soil temperature on both sites as well as lower soil moisture (see Element 4 - Phenophase Description and Documentation).

Another similarity was the manner in which different species accumulated their diameter growth. This consistency held for both study sites. Northern red oak accumulated 25%, 50%, and 75% of its total diameter increment before each of the three other species reached the same percentage of their diameter increment. Paper birch and bigtooth aspen grew slower than red oak, taking approximately one to two weeks more to reach the same level of growth. Red maple was the slowest of the four tree species to put on diameter growth; it was generally later than paper birch and bigtooth aspen by an additional week. Again, all species were the same by the time 90% of total diameter growth had been achieved.

The smaller diameter trees within a species generally grew faster than the larger diameter trees, accumulating between 40% to 70% of their total diameter growth before the larger diameter trees caught up. Figures 3.7 and 3.8 provide examples of this pattern. Larger diameter trees generally finished accumulating 90% to 100% of their total diameter growth slightly earlier than the smaller trees. This was generally the case for each species.

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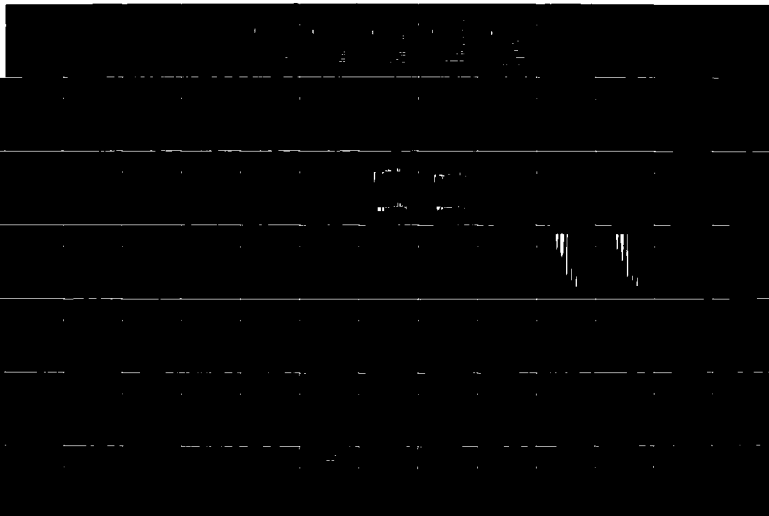
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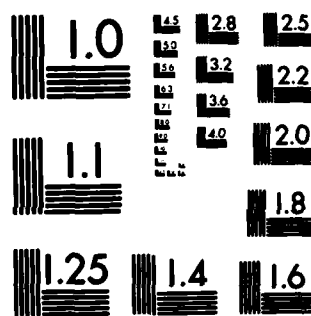
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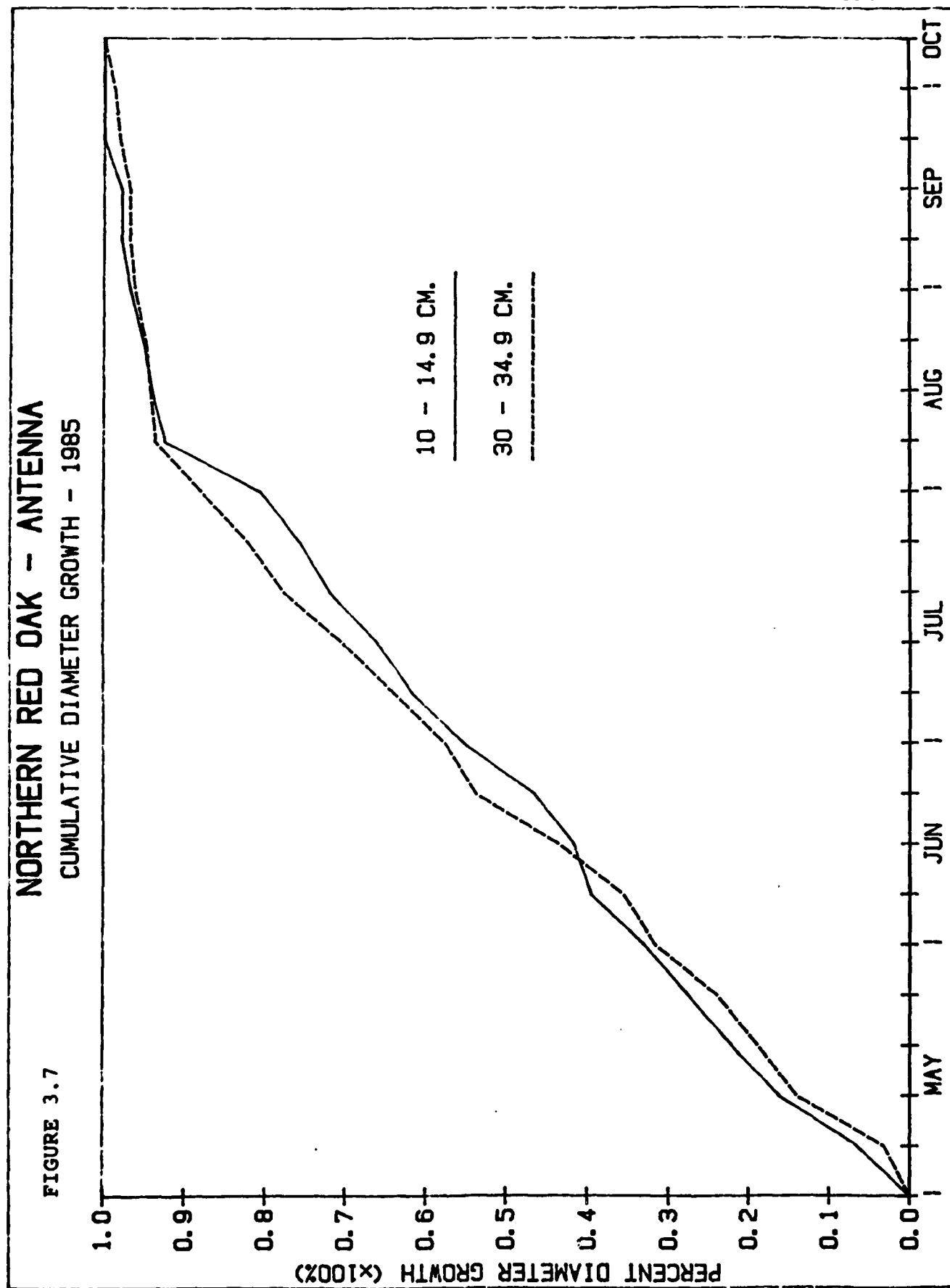


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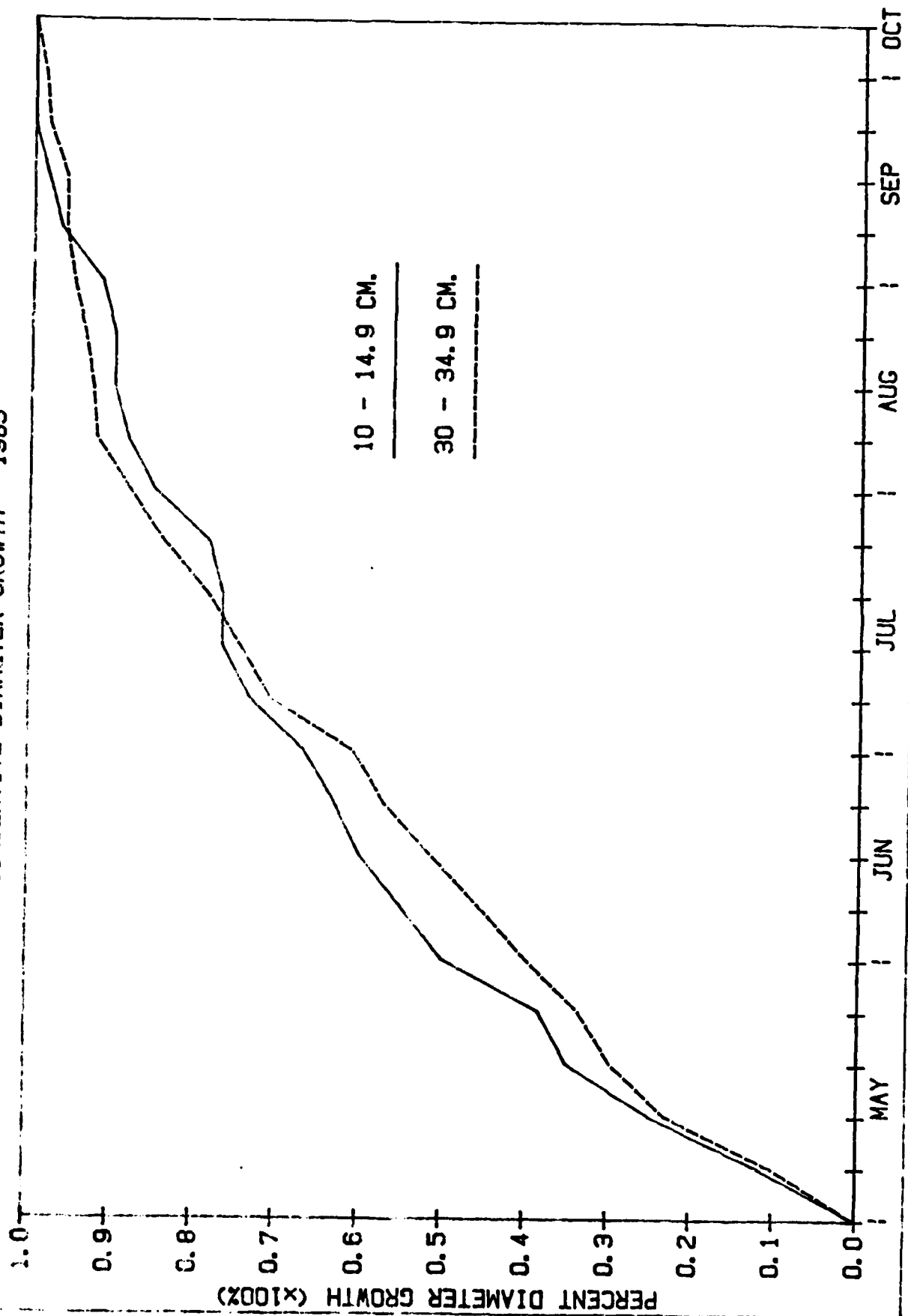
**NORTHERN RED OAK -- ANTENNA**  
**CUMULATIVE DIAMETER GROWTH - 1985**

FIGURE 3.7



NORTHERN RED OAK - CONTROL  
CUMULATIVE DIAMETER GROWTH - 1985

FIGURE 3.8



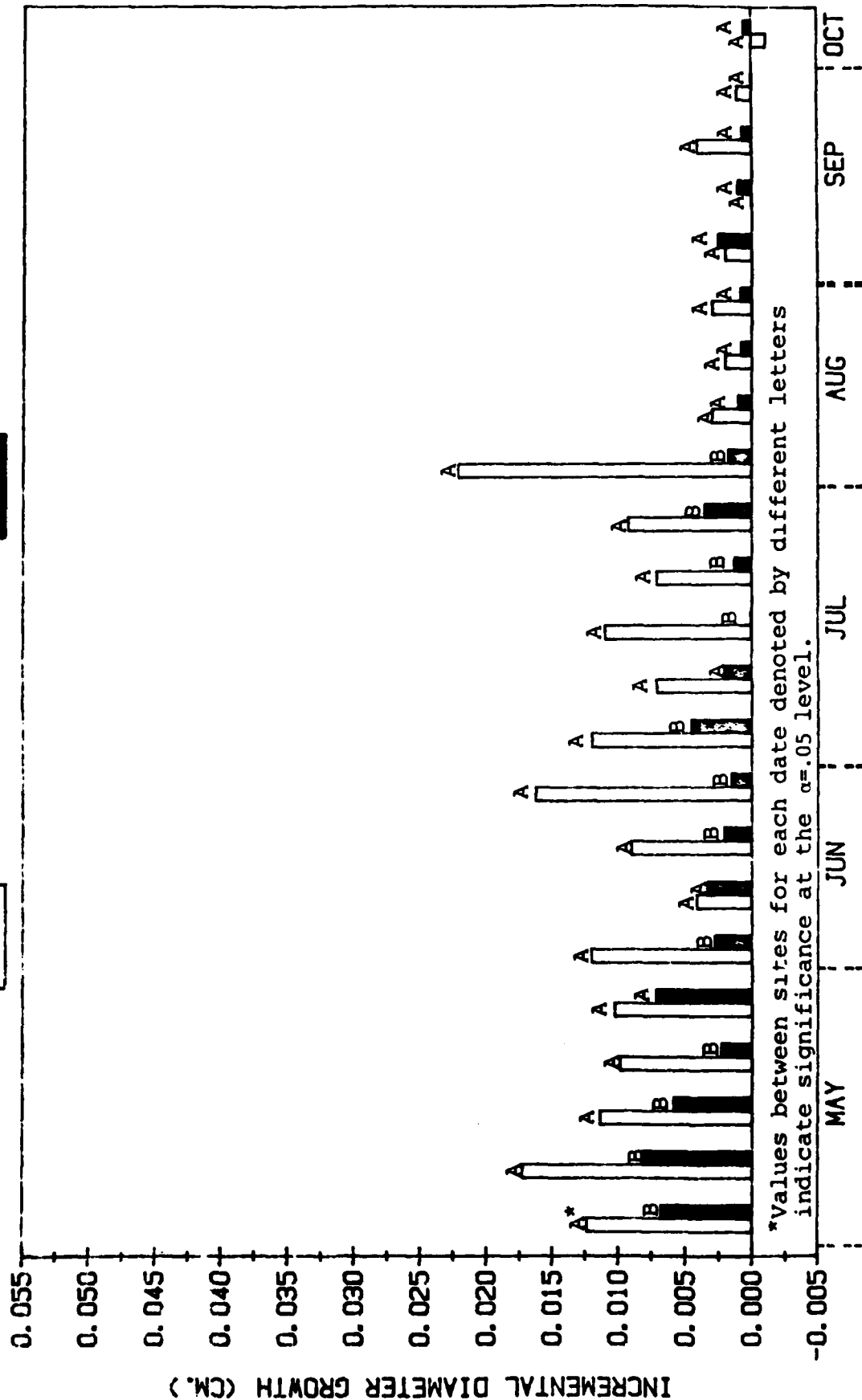
### Analysis of Diameter Growth Within 1985

Levels of diameter growth within the 1985 growing season were examined to determine at which week or weeks they significantly differed between sites. Again, because 1984 data was not readjusted, comparisons of weekly growth are not available at this time. Diameter at breast height, total height, and basal area proved insignificant as covariates. Differences in site were generally found in all diameter classes of *northern red oak* until the end of July and the first part of August. At this time approximately 75% to 90% of the total diameter increment had been completed and growth was tapering off. Figures 3.9 through 3.13 show the average incremental growth put on by *northern red oak* in each diameter class. Incremental growth of other species are illustrated in Appendix D.

Paper birch diameter growth started more slowly than *northern red oak*, with 25% of the total diameter growth generally accumulated by the first two weeks of June. At this point, site differences in diameter increment occurred and continued until about the end of July when approximately 80-90% of total growth has accumulated. For *bigtooth aspen*, site differences in incremental growth occurred early in the growing season and continued until growth tapered off (end of July). *Red maple* grew more slowly than the other four species and significant site differences in incremental growth did not arise until the end of May when 10% to 15% of the total diameter growth had occurred. Significant differences between sites continued until the middle of July when approximately 50% to 60% of total diameter increment was completed. The variability in these analyses is high and only shows comparisons between sites within one year. Development of regression models from several years of data will allow the examination of changes in diameter growth on a site from year to year and determine if there are significant differences. Site differences from week to week do exist since weekly

FIGURE 3.9      **NORTHERN RED OAK - 1985**  
 INCREMENTAL GROWTH FOR 10.0 - 14.9 CM. DIAMETER CLASS  
 MAY 1 - OCT 10

ANTENNA  CONTROL 

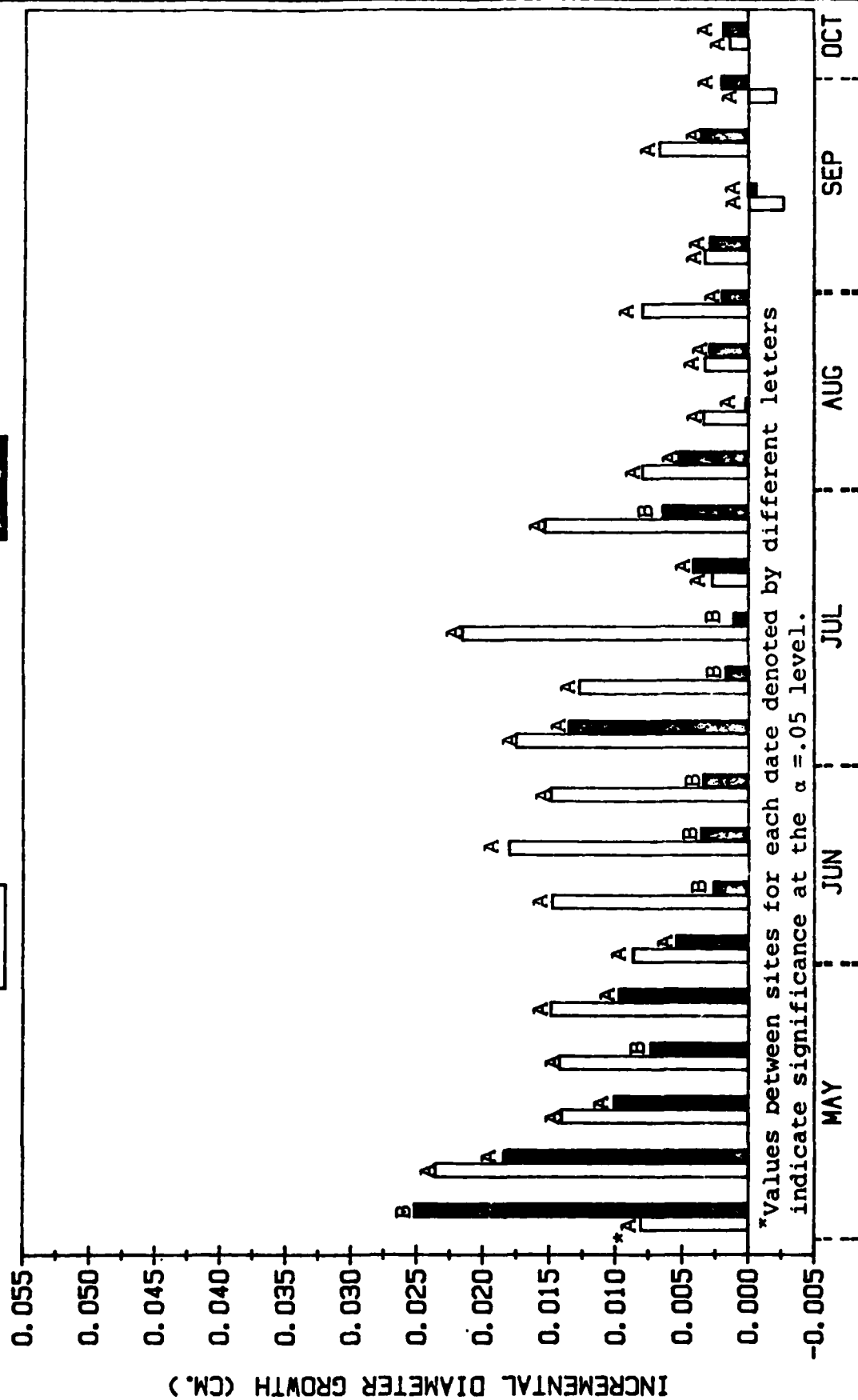


# NORTHERN RED OAK - 1985 INCREMENTAL GROWTH FOR 15.0 - 19.9 CM. DIAMETER CLASS MAY 1 - OCT 10

FIGURE 3.10

ANTENNA

CONTROL



**FIGURE 3.11**  
**NORTHERN RED OAK - 1985**  
**INCREMENTAL GROWTH FOR 20.0 - 24.9 CM. DIAMETER CLASS**  
**MAY 1 - OCT 10**

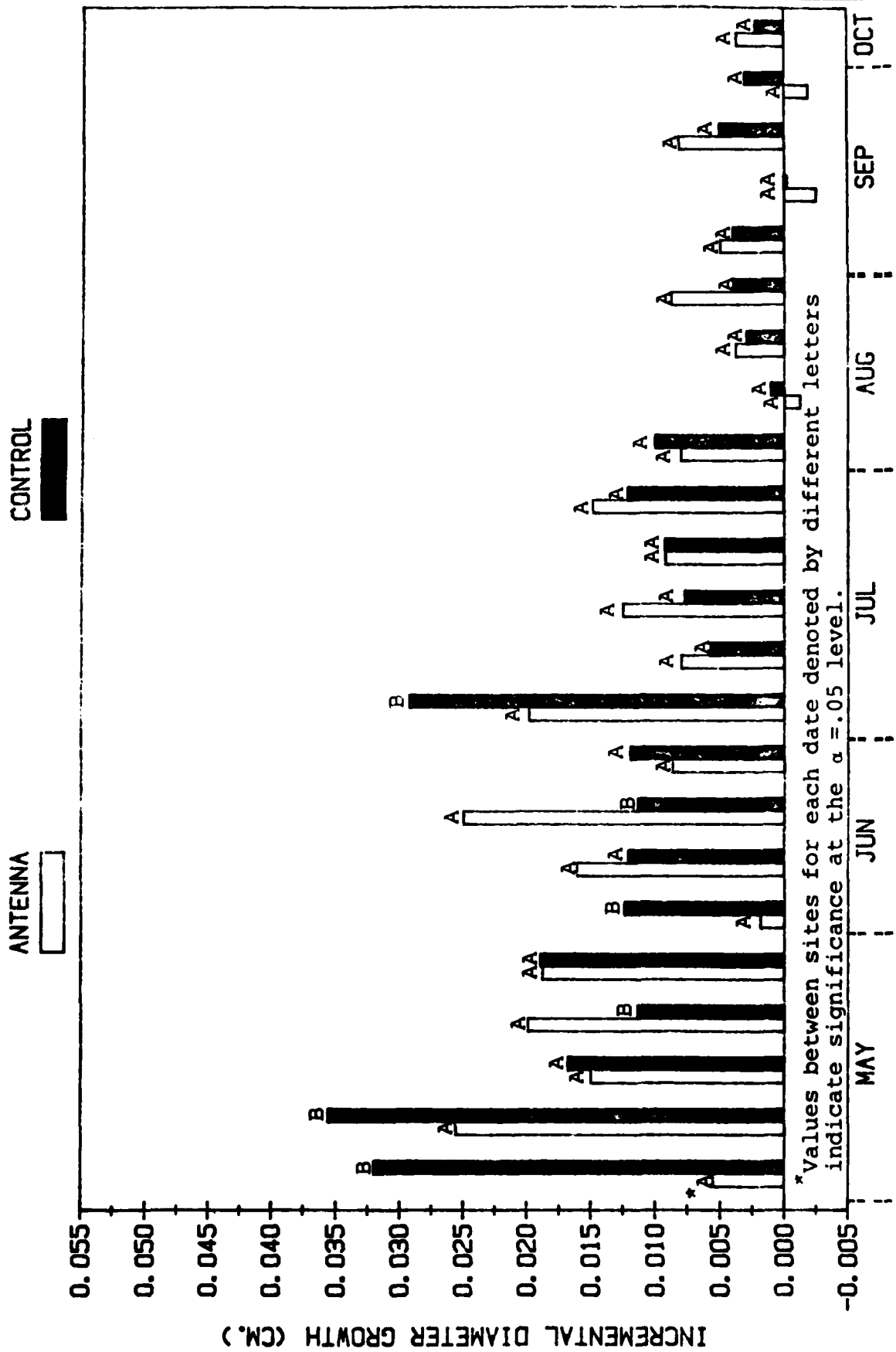


FIGURE 3.12  
**NORTHERN RED OAK - 1985**  
 INCREMENTAL GROWTH FOR 25.0 - 29.9 CM. DIAMETER CLASS  
 MAY 1 - OCT 10

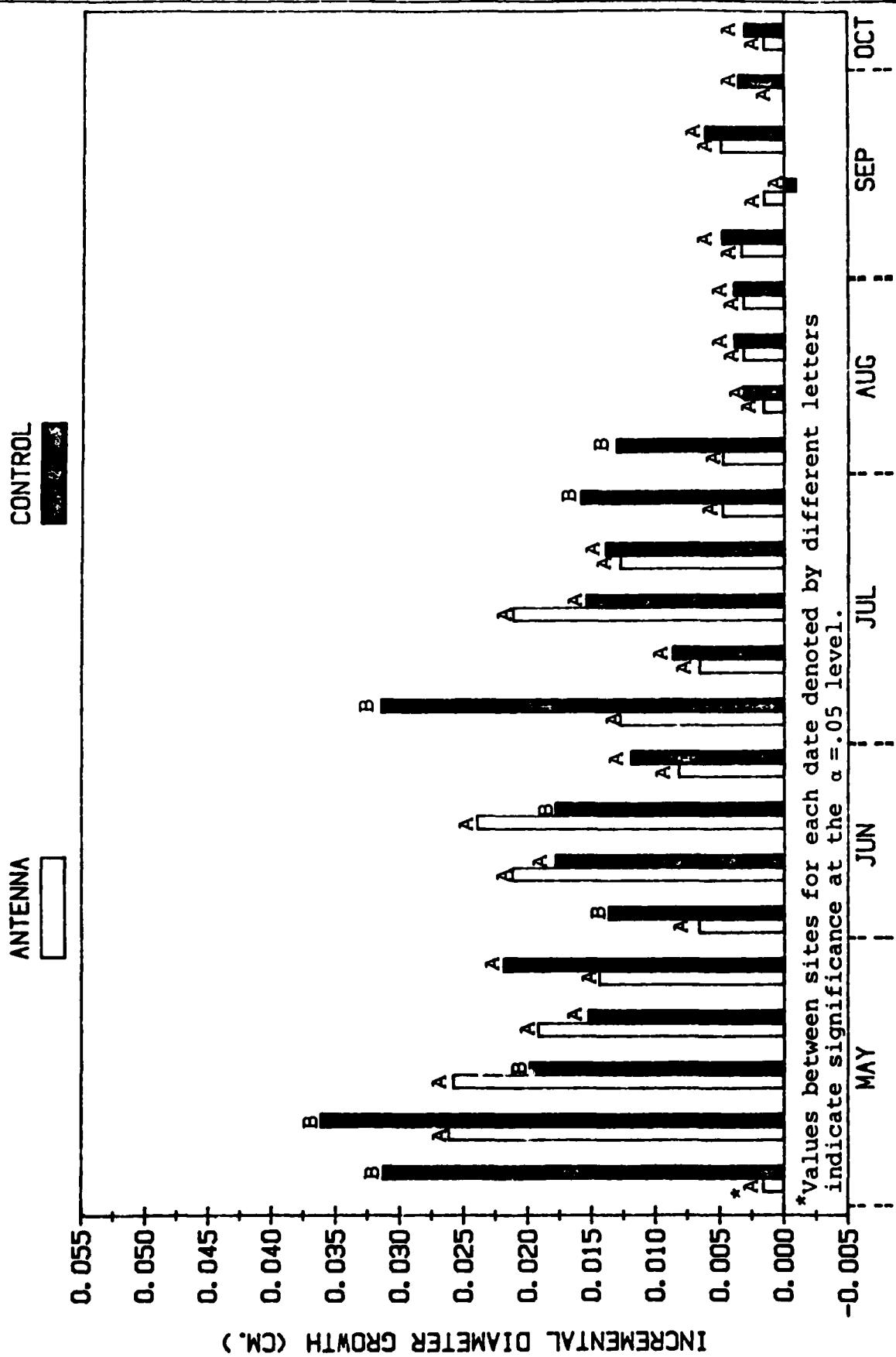
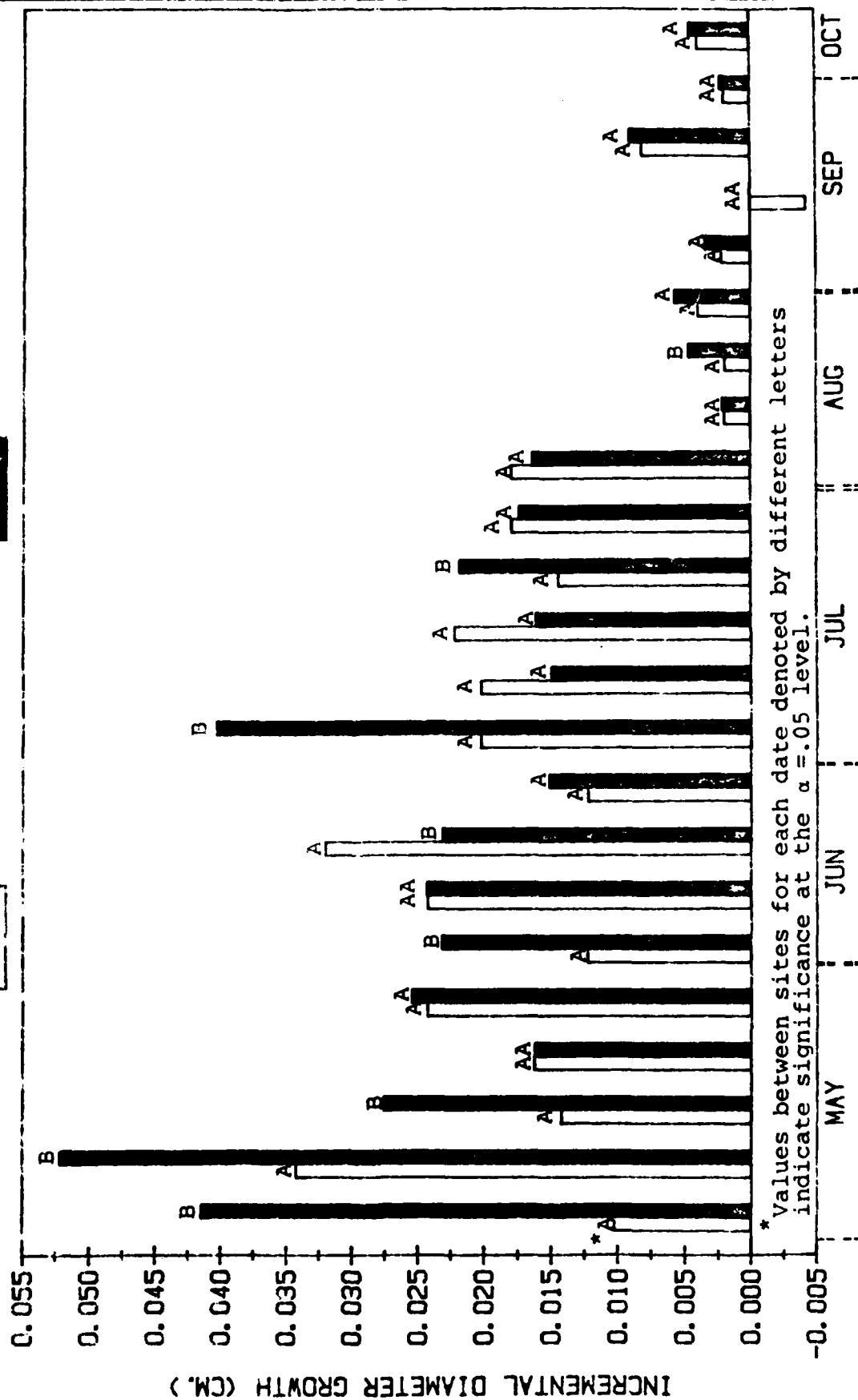


FIGURE 3.13

# NORTHERN RED OAK - 1985 INCREMENTAL GROWTH FOR 30.0 - 34.9 CM. DIAMETER CLASS MAY 1 - OCT 10

ANTENNA

CONTROL





incremental growth is so variable and the number of trees of a given species on each site differs greatly, but yearly patterns of the rate of growth for each site can be established and examined from year to year.

With two years of diameter increment measurements of four tree species, it is apparent that some site differences exist within several diameter classes. The next step in analyzing the data is to determine if the differences or variability in the two sites can be explained through covariates. Care must be taken to insure that those covariates deemed significant in explaining site variability are independent of site treatment (exposure to ELF fields). The range of possible covariates is wide and may vary for each species as well as each diameter class. Tree and stand measurements such as crown position, previous year's diameter increment (prior to an operational ELF antenna), number of stems per hectare, and site index need to be examined. Site variables such as air temperature, number of degree days above 4.4°C, precipitation, and solar radiation must also be examined. Relationships of covariates with diameter increment must be linear (an assumption of the analysis of covariance) and transformations or combinations of these variables may also be necessary. Finally, too many covariates in the analyses may be less effective than using a few, thus care must be taken to obtain the combination of covariates which best explains existing site variability.

#### Growth Model Comparisons

An important step in evaluating the growth models discussed here was the examination of existing models to determine whether they could provide better estimates of diameter growth on the study sites. Three existing models were tested using data from the antenna and control sites. If any of these provided adequate diameter growth estimates, they could then be examined as an alternative to the new model. None of the existing models

have the capability to estimate seasonal growth pattern, but all do estimate the level of annual growth.

The first diameter growth model tested was a general model developed in the Lake States Region using simple stand parameters as predictors (U.S.D.A., 1979). This model was part of a forest growth projection system developed by the North Central Forest Experiment Station to be used as the core of the Forest Resources Evaluation Program (FREP). The model predicts average annual diameter growth by species using initial tree diameter, tree crown ratio, and plot site index. The model form and coefficients used for each species are shown in Appendix E.

The two other growth models tested were more detailed than the first model. The first of these (JABOWA) was developed by Botkin et al. (1972) and is a direct extension of the Hubbard Brook ecosystem study. The second (FORET), developed by Shugart and West (1976), was a modification of JABOWA and was used to study the impact of chestnut blight in Tennessee. Both use the same general procedures but different coefficients and parameters for the specific species in their area of interest. Each uses an potential diameter growth equation based on tree diameter and maximum tree height for each species and a growth rate parameter (G). Potential diameter growth is then modified according to measures of available light, stand biomass, and growing degree days. Appendix E shows the growth model and modifiers used for all equations tested, and the coefficients and parameters used in the analysis.

Table 3.5 shows the results of the three models as they compare to the observed diameter growth of the 1985 season. Proportion variation explained (PVE) was the test statistic used to evaluate model performance. Also included in these tables is the percent variation of the residual from the observed annual growth indicating whether or not the model overestimated or

Table 3.5. Test statistics for existing models.

U.S.D.A. model	Average Residual (cm)	Standard Dev. Residual (cm)	PVE(%)
<u>Control</u>			
Red Oak	-.205(-101%) <sup>A/</sup>	.175	-2.33
Paper Birch	-.285(-370%)	.072	-12.67
Big Tooth Aspen	-.124(-41%)	.112	-1.03
Red Maple	-.233(-114%)	.167	-17.45
Quaking Aspen	-.211(-98%)	.148	-2.51
<u>Antenna</u>			
Red Oak	-.193(-79%)	.155	-1.57
Paper Birch	-.250(-129%)	.077	-5.98
Big Tooth Aspen	-.117(-31%)	.189	-.69
Red Maple	-.321(-233%)	.102	-8.86
Potential JABOWA model			
<u>Control</u>			
Paper Birch	-.356(-462%)	.145	-22.32
Red Maple	-1.293(-634%)	.064	-526.96
<u>Antenna</u>			
Paper Birch	-.220(-113%)	.147	-6.12
Red Maple	1.404(-1017%)	.110	-171.15
Modified JABOWA model			
<u>Control</u>			
Paper Birch	-.232(-301%)	.137	-10.47
Red Maple	.104(51%)	.056	-3.43
<u>Antenna</u>			
Paper Birch	.008(4%)	.114	-.34
Red Maple	.068(49%)	.107	-.40

Table 3.5 (continued)

Potential FORET model	<u>Average Residual (cm)</u>	<u>Standard Dev. Residual (cm)</u>	<u>PVE(%)</u>
<u>Control</u>			
Northern Red Oak	-.431(-213%)	.110	-10.46
Red Maple	-1.135(-556%)	.062	-406.33
<u>Antenna</u>			
Northern Red Oak	-.402(-165%)	.151	-6.76
Red Maple	-1.244(-901%)	.108	-133.98
Modified FORET model			
<u>Control</u>			
Northern Red Oak	.039(19%)	.126	-.01
Red Maple	.095(47%)	.056	-2.83
<u>Antenna</u>			
Northern Red Oak	.057(23%)	.153	-.12
Red Maple	.043(31%)	.107	-.16

<sup>A</sup> given as percent of observed average

underestimated annual diameter growth for a given species and site.

The general Forest Service diameter growth model overestimated growth for all species on both sites. It performed best on bigtooth aspen at both sites and the worst on red maple at both sites. All values for PVE were less than zero indicating that the use of this model would be no better than using the average growth as a predictor of annual increment.

The second model tested was the JABOWA model. The only species to which it could be applied were paper birch and red maple since coefficients were not available from the original model formulation for the other species in this study. Comparisons were made using both the potential diameter growth and the modified growth. As expected, the potential growth overestimated observed diameter growth by a large margin, thus resulting in a very large negative PVE. Generally, the modified growth performed better against observed growth with positive residuals and lower PVE values. The JABOWA performed better than the Forest Service growth model but it still lacks the performance desired to be used as an indicator of northern hardwood diameter growth.

The last model considered was FORET. This model could only be used for red oak and red maple. The FORET model performed much the same as JABOWA. It greatly overestimated diameter growth using the potential diameter growth, but gave much better results after modification. In general, it performed better than the other two models, but still not well enough to be considered as a viable alternative to developing a site specific model for northern hardwoods.

## PLANTATION STANDS

### Red Pine Seedling Growth

The overall objective in this phase of the Tree Productivity studies is 1) to collect baseline data on red pine seedling growth prior to operation of the ELF antenna system, and 2) use this data to evaluate possible changes in red pine seedling growth and survival due to ELF electromagnetic fields. Since young trees exhibit rapid growth rates, possible effects on growth due to ELF may be more easily detected on seedlings than on older more slowly growing individuals. Other justifications for investigating red pine seedlings are: 1) the response to Michigan DNR concerns over lack of monitoring on forest regeneration, 2) the lack of sufficient natural conifer regeneration on the study sites for mycorrhizal studies, and 3) the magnetic fields associated with the antenna ground rapidly decrease over a short distance. Construction of the ground antenna through a red pine plantation would allow study trees to be closer to the electromagnetic source than would any mature tree plot requiring a buffer strip of trees along the right-of-way. Red pine plantations would thus be configured to subject seedlings to specific ELF electromagnetic field strengths.

The evaluation of red pine seedling growth is divided into two areas: 1) the determination of annual growth, vigor, and survival, and 2) the evaluation of seedling growth patterns as a function of time and climatic factors. This second topic is presented in detail in Element 4. Phenophase Description and Documentation. The discussion presented in this section will be limited to data concerning annual red pine seedling growth. The two overall null hypotheses tested in this phase of the study are:

$H_0$ : There is no difference in the level or the rate of diameter growth

on planted red pine seedlings before and after the ELF antenna becomes operational.

$H_0$ : There is no difference in the level or the rate of total height growth on planted red pine seedlings before and after the ELF antenna become operational.

In addition, diameter and total height will be measured to establish relationships between the sampling sites. The null hypotheses tested are:

$H_0$ : There is no difference in the level or the rate of diameter growth on planted red pine seedlings between the ground, antenna, and control sites within a year.

$H_0$ : There is no difference in the level or the rate of total height growth on planted red pine seedlings between the ground, antenna, and control sites within a year.

The resulting ANOVA table is the same for both diameter and height growth and is shown below:

Table 3.6. ANOVA table for red pine seedling growth studies.

<u>Source of Variation</u>	<u>df</u>	<u>SS</u>	<u>MS</u>	<u>F</u>
Plot	2	SS <sub>p</sub>	MS <sub>p</sub>	MS <sub>p</sub> /MS <sub>E(S)</sub>
Site	2	SS <sub>s</sub>	MS <sub>s</sub>	MS <sub>s</sub> /MS <sub>E(S)</sub>
Error(S)	#seedlings-9		MS	
Year	#years-1	SS <sub>y</sub>	MS <sub>y</sub>	MS <sub>y</sub> /MS <sub>E(Y)</sub>
Site x Year	(2)(#years-1)	SS <sub>SY</sub>	MS <sub>SY</sub>	MS <sub>SY</sub> /MS <sub>E(Y)</sub>
Error(Y)	(#seedlings-9)+8(#yrs-1)	SS <sub>E(Y)</sub>	MS <sub>E(Y)</sub>	

### Sampling and Data Collection

In order to meet the objectives and address the concerns mentioned above, a small area was cleared of existing vegetation at the ground and antenna sites in June, 1984. A similar clearing was created at the control site which would also function as a sham right-of-way. Diagrams of each study site showing the clearings and their relationship to the polesized

tree plots and the ELF system can be found in Appendix G. These clearings were immediately planted with 3-0 stock red pine seedlings from a Dickinson County seed source. Seedlings were hand planted on a 1 m by 1 m spacing. This density would provide adequate numbers of seedlings for destructive sampling throughout the study period, allow for natural mortality, and leave a fully stocked stand when the study is completed. A summary of the clearing and planting operations appears in Table 3.7.

Table 3.7. Summary of clearing and planting operations 1984

<u>Site</u>	<u>Size of Cleared Area</u>	<u>Number of Seedlings Planted</u>
Ground	4.4 ac	8,000
Antenna	3.8 ac	7,000
Control	3.3 ac	6,000
Total	11.5 ac	21,000

Three plots were then established on each plantation. At the antenna and ground sites, these were located as close as possible to the ELF system (See Appendix G). Three hundred red pine seedlings were permanently marked at the ground, antenna, and control sites (total of 900 trees) and were measured at the end of the 1984 and 1985 growing seasons. The following information was recorded for each seedling:

- Basal diameter (cm)
- Total height (cm)
- Presence of terminal bud formation
- Condition % of red needles (1984 only)
- Terminal bud length (1985 only)
- 1985 growth (cm)
- Seedling microsite (1985 only)

In 1984 a wide range of red needles resulted from planting shock and was used as an indicator of seedling condition at the end of the growing season. Seedlings surviving in 1985 exhibited few red needles, thus



stratifying the sample by the percentage of red needles was not appropriate as was done in 1984.

Terminal bud length, diameter, and height growth were not measured in 1984 due to planting shock and an abbreviated growing season (seedlings were planted at the end of June). These measurements therefore, did not reflect the entire range of environmental conditions that existed for the total growing period. Bud formation and number of primordial cells within the bud are determined by the conditions existing during the current growing season. Primordial cell elongation (height growth) is largely dependent on conditions existing in the following year (Strothmann, 1967). Because 1985 was the first complete year for collection of red pine and ambient data, its inclusion as previous years covariates in the data analysis will be delayed until the 1986 growing season data has been collected. However, descriptive summaries of 1984 and 1985 measurement and site comparisons for 1985 will be presented.

### Progress

Mean basal diameter and mean total height of red pine seedlings at the end of the 1984 and 1985 growing seasons are presented in Table 3.8. The control site exhibits both larger diameter and greater height than the antenna and ground sites. Standard deviation for both measurements are small relative to their means. Sample size has declined from 1984 due to mortality of 43 percent at the ground site, 37 percent at the antenna site, and 28 percent at the control. Sample sizes estimated to maintain bounds within 10 percent of the mean indicate a sufficient number of seedlings have survived to provide reliable measurements of diameter and height in the future.

**Table 3.8. Mean basal diameter and total height of red pine seedlings at the end of the growing season.**

		<u>Diameter</u>		<u>Total Height</u>	
		<u>x (cm)</u>	<u>Std. Dev.</u>	<u>x (cm)</u>	<u>Std. Dev.</u>
<b>1984</b>					
Ground	(n=300)	.45	.12	16.8	4.6
Antenna	(n=300)	.44	.10	16.6	3.9
Control	(n=300)	.46	.10	17.9	6.3
<b>1985</b>					
Ground	(n=170)	.73	.19	22.7	6.2
Antenna	(n=188)	.69	.16	23.9	6.8
Control	(n=217)	.79	.19	28.3	8.0

Red pine seedling diameter and height growth differed significantly between the ground and control sites in 1985. The antenna site did not differ significantly from either the ground or control sites. These differences are attributable to several soil and climatic factors which are discussed in detail in Element 4 - Phenophase Documentation. Variation in both height and diameter growth is relatively high with respect to the mean. However, sample size of surviving seedlings remains adequate to estimate growth within the bounds of estimation (Table 3.9).

**Table 3.9. Mean diameter and height growth of red pine seedlings.**

Site	Mean(cm)	Std. Dev.	n	Bounds of Estimation(cm)	% of <sup>1/</sup> mean	Estimated <sup>2/</sup> Sample Size
<u>DIAMETER</u>						
Ground	.27 <sup>A 3/</sup>	.142	170	.022	8.0	120
Antenna	.25 <sup>AB</sup>	.103	188	.015	6.1	65
Control	.32 <sup>B</sup>	.153	217	.020	6.4	88
<u>HEIGHT</u>						
Ground	6.9 <sup>A</sup>	3.78	170	.610	8.9	116
Antenna	8.1 <sup>AB</sup>	4.29	188	.645	7.9	107
Control	10.6 <sup>B</sup>	5.46	217	.736	6.9	102

<sup>1/</sup> Percent of mean within which estimation is possible

<sup>2/</sup> Sample size calculated to maintain a bound within 10% of the mean

<sup>3/</sup> Values in columns for each variable denoted by different letters are significantly different at  $\alpha=.05$ .

To further document environmental factors that contribute to natural variation in red pine seedling growth, the microsite occupied by each seedling was identified. Microsite categories identified were:

1. Mineral soil
2. Decayed wood
3. Mineral soil, decayed wood within 30 cm
4. Mineral soil, tree stump within 30 cm
5. Excessively rocky mineral soil
6. Excessive vegetative competition, mineral soil
7. Mineral soil, skid trail

Mean 1985 diameter and height growth by microsite category are presented in Table 3.10. The effect of these microsities on growth is inconclusive due to the small number of samples within some categories and the relatively large variation in the growth data (Table 3.8). The majority of seedlings (approximately 80%) on each site were found in the mineral soil category.

Although no obvious differences in growth by category exist at this time we will continue to monitor the microsite of each seedling in the future. Ideally, we would like to eliminate as much of the microsite variation in growth as possible. By doing so, any effect on growth due to ELF would not be masked by effects of microsite. If differences between categories are detected in the future, samples in those categories could be excluded from growth analysis. Sufficient number of seedlings in the mineral soil category insure adequate sample size for growth studies in the future even if all other categories must be eliminated from the study.

Table 3.10. 1985 Red Pine Seedling Diameter and Height Growth by Microsite Category.

<u>Seedling Microsite</u>	<u>Mean Diameter Growth(cm)</u>		<u>Mean Height Growth(cm)</u>	
	<u>Ground</u>	<u>Antenna</u>	<u>Ground</u>	<u>Antenna</u>
Mineral Soil	.27(135) <sup>1/</sup>	.25(154)	6.8(135)	8.4(154)
Decayed Wood	.31(6)	.17(1)	6.2(6)	3.1(1)
Mineral Soil, decayed wood within 30 cm	.36(3)	.25(2)	7.1(3)	2.9(2)
Mineral Soil, stump within 30 cm	.22(9)	.28(11)	5.5(9)	8.5(11)
Excessively Rocky Mineral Soil	.32(10)	.28(1)	9.9(10)	13.7(1)
Excessive Competing Vegetation over Mineral Soil	.16(5)	.19(6)	5.5(5)	6.2(6)
Mineral Soil, Skid Trial	.56(2)	.25(13)	9.6(2)	6.2(13)
				9.5(20)

<sup>1/</sup>Numbers in parentheses indicate sample size.

### Seedling Moisture Stress

Field measurement of plant moisture stress (PMS) is useful as a physiological indicator of seedling vigor and as a possible covariate in seedling growth analyses. To determine the usefulness of this measure as a covariate, a support study was conducted to evaluate the effects of PMS on seedling growth. The objectives of this study were to determine what aspects of seedling growth are most affected by moisture stress, at what critical levels of PMS are there measureable growth differences, and to quantify the PMS/growth relationship prior to and after the operation of the ELF antenna.

### Sampling and Data Collection - Field Study

Seedling moisture stress sampling was modified from the methods used in 1984. Since the purpose of this study is to monitor the physiological status of red pine seedlings, only actively growing individuals were selected. By doing this, the need to classify seedlings according to condition class as was done in 1984 was eliminated. This resulted in a less variable estimation of plant moisture stress.

Sampling was conducted monthly during the growing season. Fifteen actively growing seedlings were randomly selected on each site and a lateral shoot severed in the pre-dawn hours to test for xylem water potential using a plant moisture stress meter. Prior to PMS determination, basal diameter, length of candle elongation, height (to top of candle), and bud formation status were measured. The remaining stem and roots were excavated the afternoon following PMS determination to measure aboveground/belowground biomass (shoot-root ratios), shoot nutrient concentration, and mycorrhizae numbers (Element 7).

### Progress - Field Study

Moderate changes in seedling moisture stress are expected to reflect

fluctuations in moisture supply and demand. The summary of average values for each seedling measurements by site and sampling date is shown in Appendix H. Site and month PMS differences were tested using ANOVA techniques. Significant differences were found between sampling dates for the period of May through September ( $p = 0.000$ ). Table 3.11 shows PMS means for each site and sampling date. PMS values for May and September differed significantly from other months as xylem water in the pine seedlings was frozen. Analyses of PMS values for the months of June, July and August showed no significant differences between sites or months ( $p = .572$ ).

**Table 3.11. PMS means by site and sampling date**

	PMS Values (bars)				
	<u>May</u>	<u>June</u>	<u>July</u>	<u>Aug.</u>	<u>Sept.</u>
Ground	23.2	5.0	6.3	5.9	19.4
Arceutha	21.7	5.0	6.5	5.7	21.5
Control	11.0	6.4	6.8	6.4	25.5
Overall	18.6 <sup>A</sup>	5.5 <sup>B</sup>	6.5 <sup>B</sup>	6.0 <sup>B</sup>	22.2 <sup>C</sup>

\*Values across a row denoted by different letters indicate significance at the  $\alpha = .05$  level.

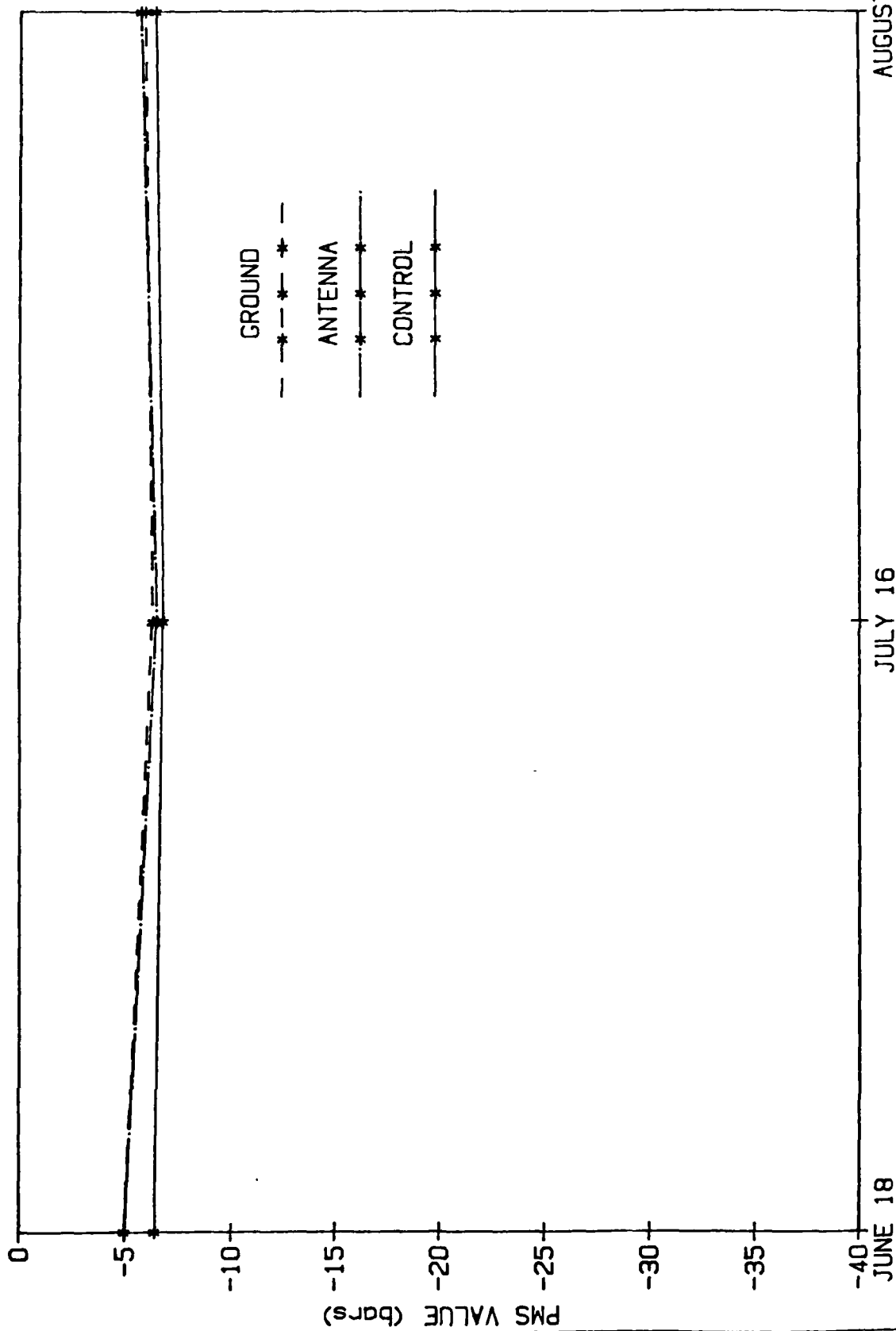
Mean values for the months of June through August coincide with those of well watered experimental seedlings and indicate negligible effects of water stress on growth during the 1985 growing season. Figure 3.14 depicts the close similarity of PMS between sites and sampling dates.

#### Sampling and Data Collection - Support Study

The experiment to evaluate effects of water stress on seedling growth was conducted with 300 potted red pine seedlings subjected to five different

# SEEDLING MOISTURE STRESS VALUES

BY SITE BY DATE



watering regimes. Moisture regimes varied from field capacity to below permanent wilting point for the study duration. A polyurethane shelter was erected over the pots to minimize additions of water from precipitation. This covering was placed in such a way to prevent reductions in air movement and its subsequent effects on plant respiration and transpiration.

### Progress - Support

Analysis of results from this experiment have not been concluded. Many of the growth variables have shown significant differences due to watering treatments. These include bud size (length and diameter), average needle length, shoot and root biomass, new-growth biomass, length of longest root, and number of active mycorrhizal root tips. Candle elongation showed no response to stress. Clements (1970) and Lotan et al (1963) reported similar results and emphasized the importance of bud development on subsequent years shoot growth. They found bud size to be more related to shoot production than environmental conditions during the year of elongation. Timing of severe water deficits played an important role in our study and is reflected in the variable growth differences.

Measures of seedling morphological characteristics have not identified any strong linear relationships with PMS. The only variable to show any significant correlation at an level of 0.01 was number of active mycorrhizal root tips per gram of root weight and this correlation was very weak ( $r = -.20$ ). This variable is an indicator of root activity and, hence the negative relationship with seedling moisture stress. Further analyses of results including foliar nutrient determination are now being conducted.

Since covariates need to be independent of treatment effects, the use of seedling moisture stress as a covariate in red pine growth analyses is still pending. Just as the phenophase description element of the study aims at



relating phenological changes to physiological changes, seedling moisture stress is also indicative of physiological abnormalities, such as changes in stomatal functioning which may be affected by ELF fields. If PMS is not independent of ELF effects, it should be monitored to detect ELF induced variation. Variation from month to month and among sites was extremely low during the 1985 sampling and would support the inclusion of this variable in detecting ELF effects.

#### ELEMENT 4. PHENOPHASE DESCRIPTION AND DOCUMENTATION

The overall objective of this element is to: 1) describe and document specific phenological events on selected tree species and herbaceous plants during the baseline study period, and 2) use this data to indicate possible changes in physiological processes due to ELF electromagnetic fields when the system becomes operable. By documenting these biological events during the baseline period, we will be able to develop a data base with which to compare similar data collected when ELF is operational. This will allow us to monitor any shifts in the timing of the selected phenophases that may be due to ELF. However, we must first be able to separate any shifts in phenophases that are due to yearly variation in weather conditions. It is important, therefore, to include detailed climatic data when describing and documenting phenophases that will be used to evaluate possible effects due to ELF. Phenophase documentation has been separated into two areas of study: 1) tree phenology, which includes red pine seedlings and hardwood species, and 2) herbaceous phenology. a detailed study of Trientalis borealis L., starflower.

##### TREE PHENOLOGY

##### Red Pine Seedlings

Since young trees often exhibit rapid growth rates, possible effects on growth due to the ELF system may be more easily detected on seedlings than on older, more slowly growing trees. Also, precise measurements of shoot elongation and bud development are more easily made on seedlings. Possible effects of ELF fields may include reduced growth rates or shifts in the timing of key biological events. Growth studies on red pine are presented in Element 3. Tree Productivity. In this section we will examine the timing of red pine height growth in 1985 and some of the basic relationships to

climatic and site factors that have been tentatively identified this first full growing season.

The overall null hypothesis for this phase of the study is:

$H_0$ : There is no difference in the timing of red pine height growth before and after the ELF antenna becomes operational.

Each year, prior to an operational antenna, the null hypothesis examined is:

$H_0$ : There is no difference in the timing of red pine height growth between the ground, antenna, and control sites within a year.

### Sampling and Data Collection

In 1984, red pine plantations were established at each site. Details concerning this process can be found in Element 3: Tree Productivity. Three hundred randomly selected seedlings were then permanently marked at the ground, antenna, and control sites for annual red pine growth measurement. From these three hundred seedlings at each site, one hundred seedlings were randomly selected for weekly measurement of height growth. Weekly measurements began on April 25, 1985, and ended on August 21, 1985.

### Progress

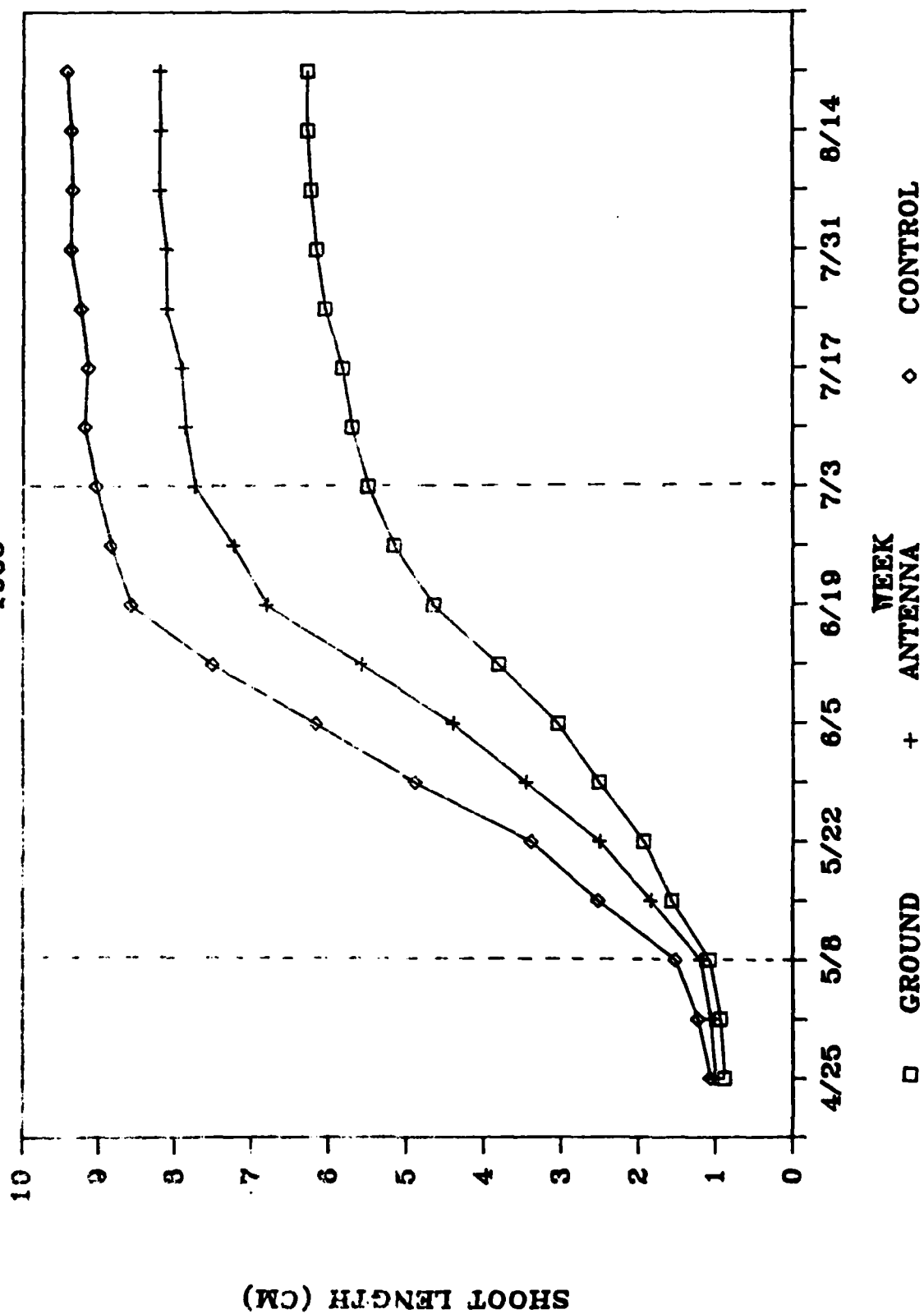
Growth patterns on each site are shown in Fig 4.1. The first three measurements represent swelling of the terminal bud with bud burst occurring between May 8 and May 15. The major growth period extends for a seven week period between May 8 and July 3.

Perala (1983) reported that the beginning and ending 5 percent of growth in 14 year old red pine was insensitive to the environment. Applying this concept to red pine seedling growth, these limits delineate the time period within which possible ELF effects would most likely be detected. Thus the growth period bounded by these limits represents the major time

# RED PINE SEEDLING GROWTH

FIGURE 4.1

1985



interval in which we will concentrate our analysis. This major growth period occurs between May 8 and July 3 and is delineated on most figures in this section by vertical dashed lines. A summary of height growth data appears in Table 4.1.

Table 4.1. Summary of red pine seedling height growth for 1985.

<u>Site</u>	<u>Total height growth (cm)</u>	<u>Percent growth 5/8 - 7/3</u>	<u># of days to reach 90% of growth</u>	<u>Growth rate (cm/wk) 5/8 - 7/3</u>
Ground	6.3	82	70	0.55
Antenna	8.2	91	56	0.81
Control	9.4	91	56	0.94

Seedlings at the ground site required 2 weeks longer to reach 90 percent of their growth than those at the antenna and control site. However, the growth rate had slowed substantially by July 3 at the ground site, and thus will be analyzed in the same time frame as the other sites. Total height growth in 1985 differed significantly between the ground and control sites, but no significant difference was found between the antenna and the other two sites. Similarly, seedling growth rates were highest on the control and lowest at the ground site.

#### Site Differences

These growth and phenological differences appear to be related to subtle physical and ambient differences among the sites. Although vegetation on each site characterizes an Acer-Quercus-Vaccinium habitat type (Coffman et al., 1983), a range of environmental conditions exist within this habitat type that contribute to the differences in seedling growth and timing of phenological events. These factors appear to be primarily soil related. The soils on the three sites are classified differently (Element 1:Plot

Selection) and reflect variations in both physical and chemical composition. Although these soils are sandy in texture and are well drained, differences exist in the finer soil fractions with the highest silt fraction at the control and lowest at the ground site (Table 4.2). Because these soils are very sandy and clay content is low on all sites, higher silt content on any site relative to the others provides for better water holding capacity which could be important to seedling growth during dry periods.

Table 4.2. Soil texture (% of fraction <2mm) and coarse fraction (rocks) (% by weight) of the upper 50 cm at the three study sites.

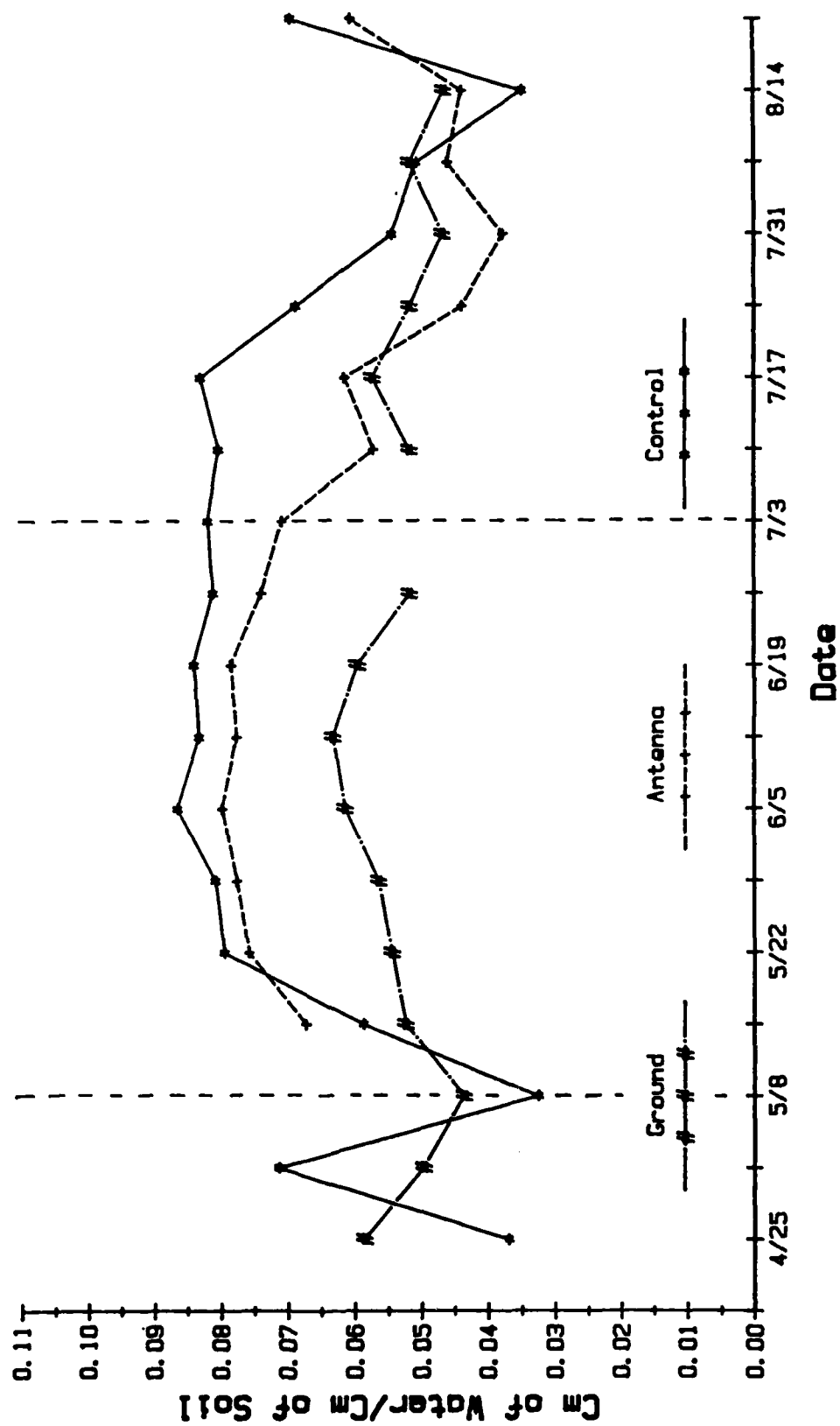
<u>Site</u>	<u>Clay</u>	<u>Silt</u>	<u>Sand</u>	<u>Coarse Fragments</u>
	- - - - % of soil <2 m- - - -			- % whole soil-
Ground	2.6	7.6	89.8	68
Antenna	1.4	9.7	89.9	13
Control	2.9	14.6	82.5	4

As discussed earlier, coarse fragments show large apparent differences among sites (Table 4.2). The reasons for our interest in coarse fragments is based on work showing that the rock fraction of the soil affects seedlings in two ways: 1) rocks reduce the volume of soil available for root growth; where rock content is excessive root penetration may be reduced, and 2) available water and soil nutrients are reduced as soil volume is reduced by the rocks.

Similarly, during the major growth period, site ranking by available soil water at 10 cm corresponds to ranking by growth (Figure 4.2). Therefore, the amount of rock present in the soil and its effect on nutrients and available soil water together with soil texture are important factors in the ranking of red pine growth among sites. Reasons for this ranking are not as clear when cumulative air temperature above 4.4°C is

# AVAILABLE WATER At 10 Cm

FIGURE 4.2



considered (Figure 4.3). The control site is significantly cooler than the antenna and ground sites during the first few weeks of the major growth period. Soil temperature at 5 and 10 cm (Figures 4.4 and 4.5) during the first few weeks of the major growth period shows a similar pattern to growth as does air temperature, but the relationship between the ground and control is not as well defined at 10 cm as it is at 5 cm. Cumulative precipitation was lower at the control than at the ground or antenna sites (Figure 2.35 - Element 2: Ambient Monitoring). The distribution of precipitation throughout the measurement period was not significantly different among the sites. Significance testing of amounts during given dates will be conducted in 1986. The factors described above combine to form a complex interaction that helps explain the ranking of red pine growth among sites. For ease of interpretation these factors are ranked by site and are shown in Table 4.3.

Table 4.3. Ranking of soil and climatic factors by site.

	<u>Ground</u>	<u>Antenna</u>	<u>Control</u>
Red pine height growth	1	2	3
Silt content %	1	2	3
Rock content %	3	2	1
Soil nutrients	1	2	3
Available water	1	2	3
Cumulative air temp	1	1	2
Soil temp (5 and 10 cm)	2	2	1
Cumulative precipitation	2	2	1
	1	-----	3
	Lowest		Highest

These rankings were determined by visually examining means and summarized data. Statistical testing will be conducted in 1986 and must be completed before drawing any conclusions regarding these relationships. Where



# FIGURE 4.3 CUMULATIVE TEMPERATURE ABOVE 4.4 DEGREES CENTIGRADE

(1985 GROWING SEASON)

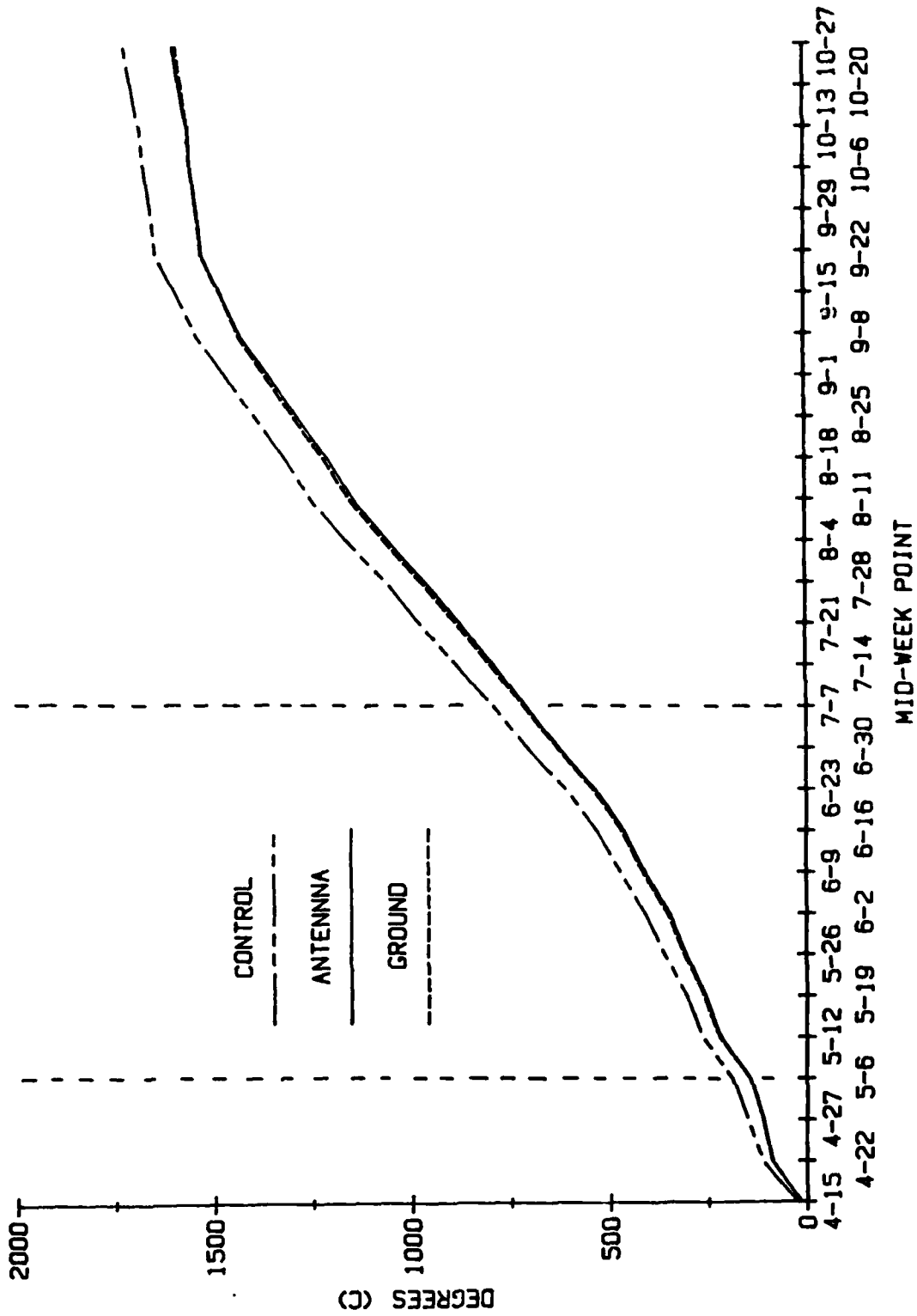


FIGURE 4.4

122.

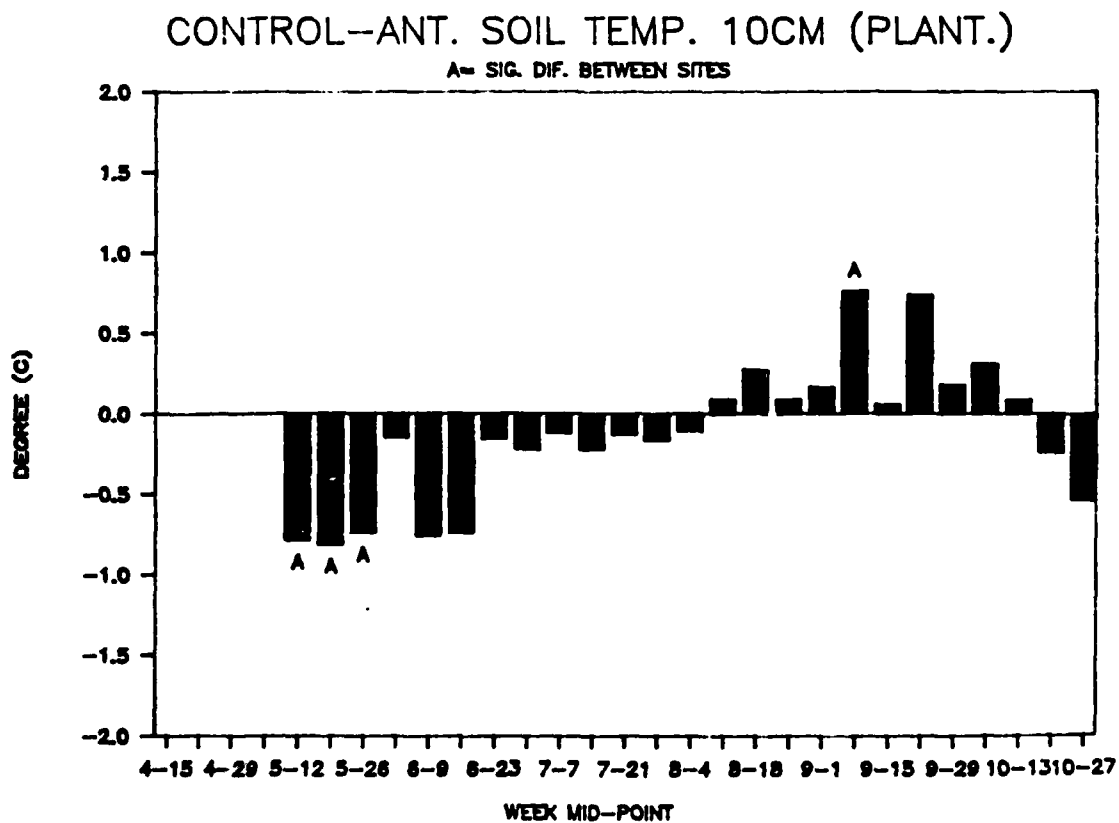
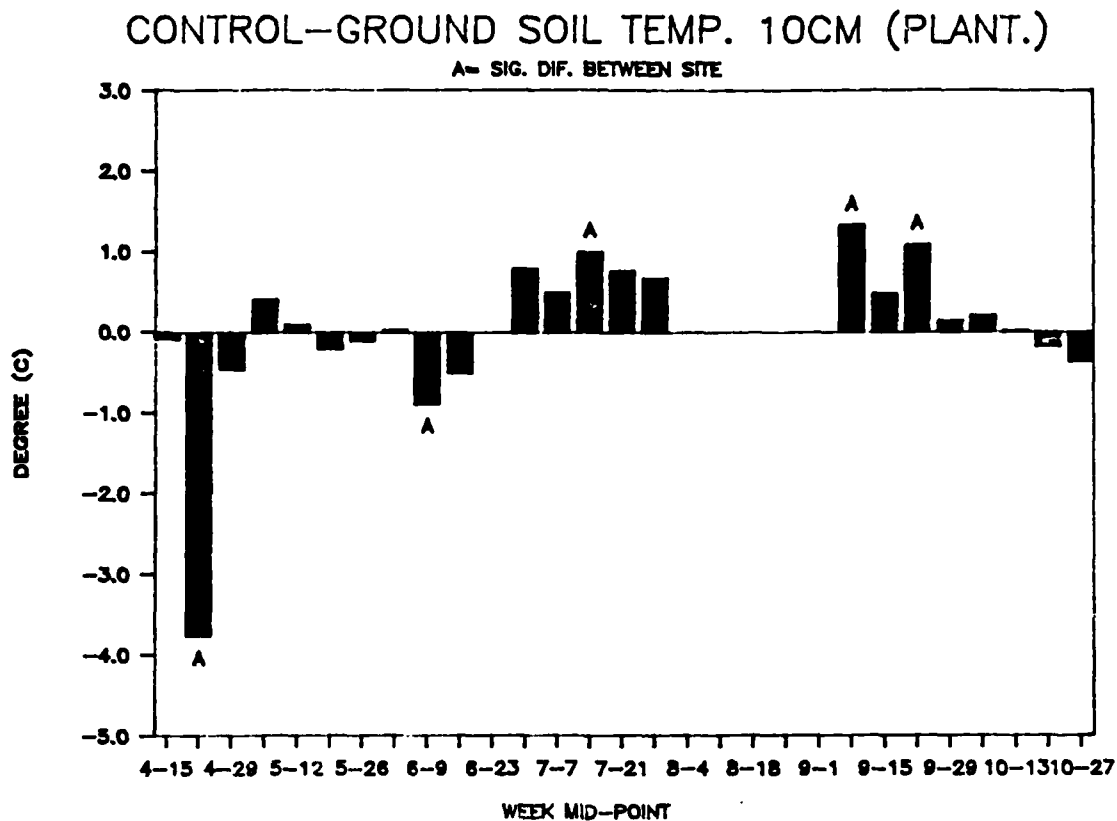
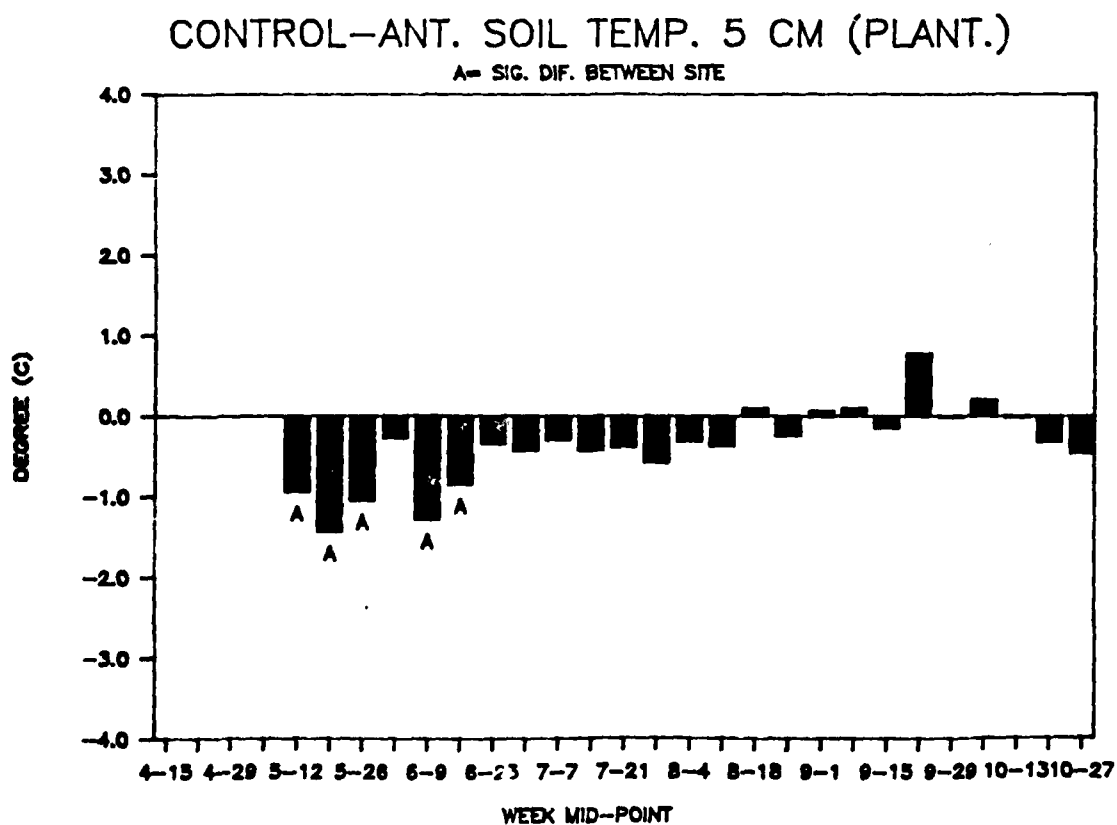
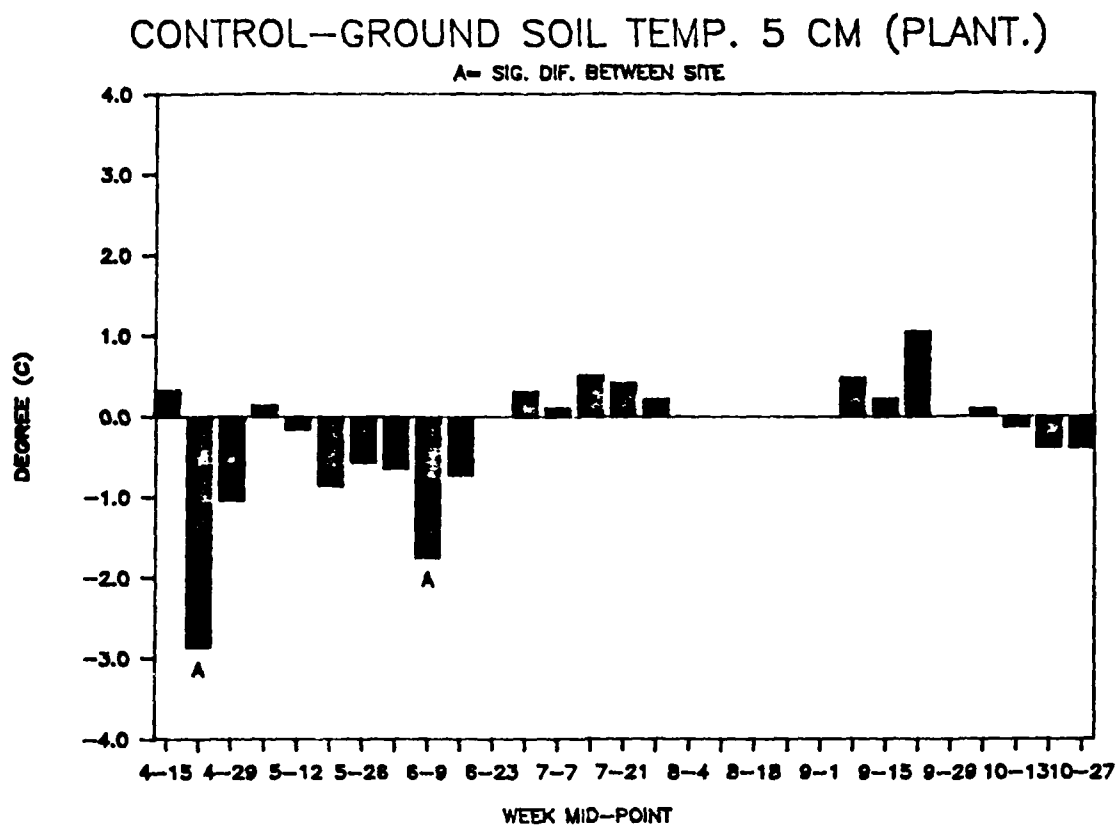


FIGURE 4.5

123.



covariate analysis will be used to determine if there is any change due to ELF fields (see Introduction: Experimental Design), regression models will be developed and tested to evaluate possible effects on growth periods; in other words, this analysis will test for changes in growth rates.

#### Growth Pattern

Although height growth varied considerably among the sites, height growth, bud burst, and slowing of growth showed similar patterns among and within sites (Figure 4.1). The site and ambient factors discussed above contribute to the growth differences among sites, but the temporal patterns of the climatic variables during the measurement period provide insight to the timing of growth events. The ambient variables that will be discussed show distinct patterns prior to bud burst, during the major growth period, and following the major growth period. These patterns are similar for each site. Average weekly air temperature (Figure 4.6) which varies considerably prior to bud burst, remains above 10°C during the major growth period. With the exception of the first week of this period, temperature rises steadily and remains between 10°C and 15°C. During the last 2 weeks, temperature increased at a faster rate until it reached 18°C at the end of the major growth period and ranged between 16°C and 18°C for the next six weeks.

Soil temperature at 5 and 10 cm (Figure 4.7) show very similar patterns throughout the measurement period. Temperatures are slightly lower at 10 cm than at 5 cm as expected. A summary of soil temperatures appears in Table 4.4.

# FIGURE 4.6 AVERAGE WEEKLY AIR TEMPERATURE (C)

1985

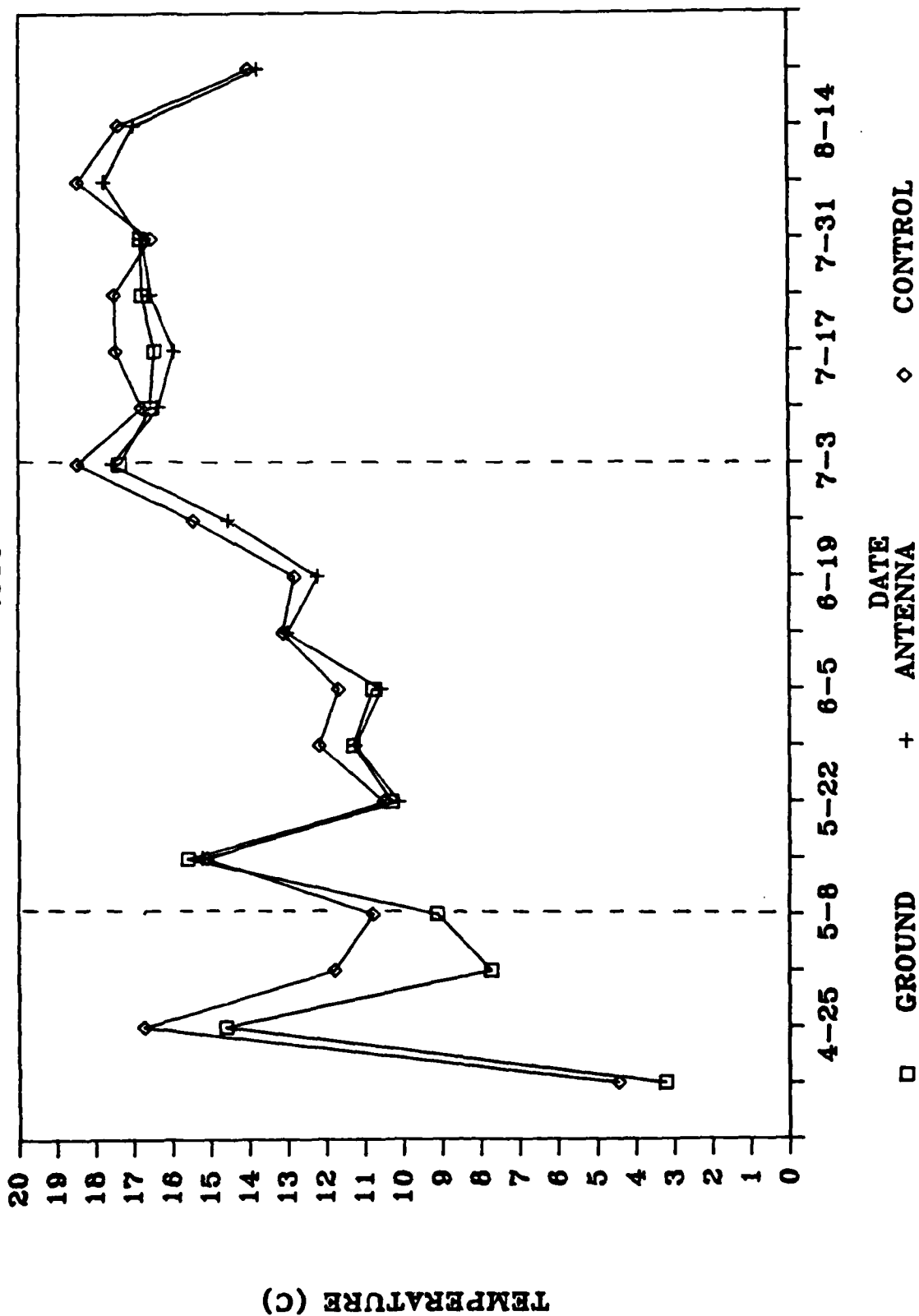
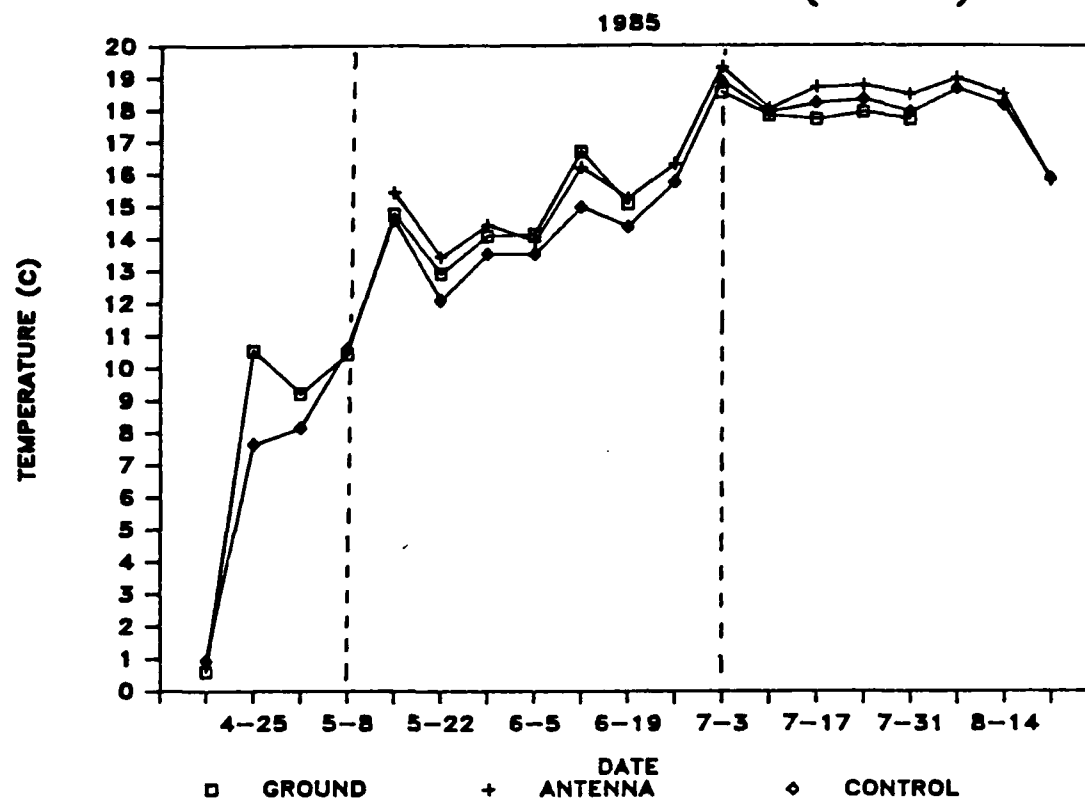


FIGURE 4.7

## SOIL TEMPERATURE (5 CM)



## SOIL TEMPERATURE (10 CM)

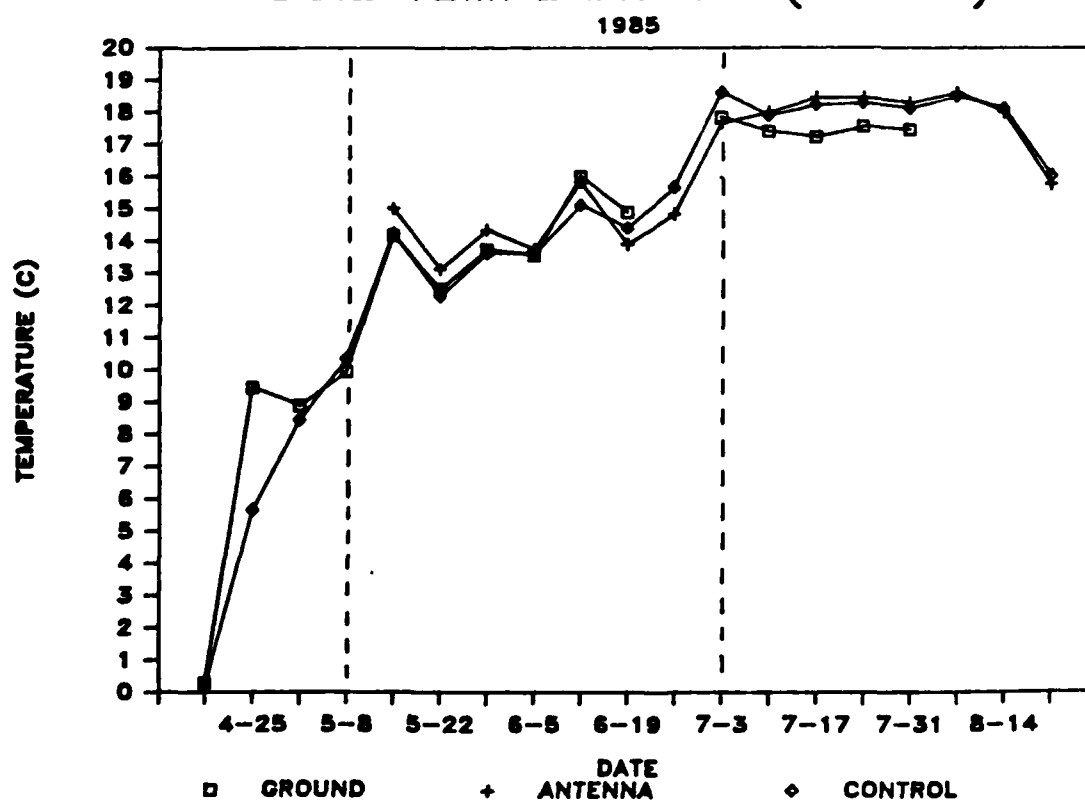


Table 4.4. Summary of soil temperatures (C°)\*.

<u>Period</u>	<u>Dates</u>	<u>5 cm</u>		<u>10 cm</u>	
		<u>Average</u>	<u>Range</u>	<u>Average</u>	<u>Range</u>
Prior to Bud Burst	4/25-5/8	9.4	7.7-10.6	8.8	5.7-10.3
Major Growth Period	5/9-7/3	15.1	12.1-19.3	14.7	12.3-18.6
Post Growth Period	7/4-8/14	18.2	17.7-19.0	18.0	17.2-18.6

\*All Sites Combined

Data from all sites were combined in the above table because soil temperature showed similar patterns at each site. Prior to bud burst, soil temperature remained below 10.6°C, between 12.1°C and 19.3°C during the major growth period, and above 17.2°C during the six weeks following.

Available soil water (Figure 4.2) shows similar variation in the pre-bud burst period as air temperature. During the major growth period, however, it increases to its highest levels and begins to decrease when soil temperatures increase. There does appear to be a lag time associated with the antenna and control sites compared to the ground. The decrease appears first at the ground followed by the antenna site and then the control site. The lag is a function of soil texture and possibly rock content that were discussed earlier. Available water decreases last on the site with the highest silt content and lowest rock content.

The relationship between site and climatic factors and the timing of specific growth events of red pine seedlings will be analyzed further in 1986. As mentioned above, a regression approach will be used to evaluate growth rates and will include climatic and site variables. Data collected in 1985 is currently being organized along with the growth data. Model development is expected to be completed by fall, 1986.

### Leaf Fall in Hardwood Species

Timing of leaf fall of hardwood species was documented throughout the growing season. The hardwood species monitored include northern red oak, red maple, bigtooth aspen, and paper birch-hazelnut. For each species, the rate as well as the total amount of leaf litter (gm) need to be examined and compared for each site and for each year. The null hypothesis tested for this study is

H<sub>0</sub>: There is no difference in the rate or the total amount of leaf litter (gm) for any given species before and after the ELF antenna becomes operational.

The hypothesis tested each year to characterize sites prior to an operational antenna is

H<sub>0</sub>: There is no difference in the rate or the total amount of leaf litter (gm) for any given species between the antenna and control site within a year.

Resulting ANOVA tables for each species are similar in structure to the one illustrated in Element 8: Litter Production. Differences in rates of leaf litter fall by species will be tested by the nonparametric two-sample Kolomogorov-Smirnov test.

### Sampling and Data Collection

The timing of leaf fall of hardwood species was documented by using 15 one meter square litter traps on the antenna and control sites. Each litter trap was subdivided into two sections .25 m<sup>2</sup> and .75 m<sup>2</sup> in size. Litter was collected monthly during the summer growing season and weekly during the leaf fall period. Only leaf litter was collected from the .25 m<sup>2</sup> section and was separated by species. Samples collected from the .75 m<sup>2</sup> section were separated by leaf, wood, and miscellaneous (seeds, flowers, etc.)



components. Miscellaneous and wood components from the .25 m<sup>2</sup> section were combined with those from the .75 m<sup>2</sup> section. This material was dried at 60°C in a forced air oven and weighed. A complete description of 1985 litter production can be found in Element 8 - Litter Production.

### Progress

A summary of leaf fall percentages for 1984 and 1985 by species and sampling period appears in Table 4.5. Statistical analyses on the data has yet to be conducted. Therefore, any differences discussed have not been shown statistically significant at this point in time. Leaf fall during periods 1 and 2 is primarily the result of storm activity. If ELF fields cause a physiological change which weaken the ability of leaves to adhere to twigs, the amount of leaf fall during storm events may change. Similarly, the rate of leaf fall during the normal leaf fall period in October may also change.

The largest apparent difference in the timing of leaf fall between 1984 and 1985 occurs during the last collection period (period 5). In 1984, leaf fall was completed in period 4, but in 1985 all species took one week longer to complete leaf fall.

Red oak leaves were retained longer than the other species in both 1984 and 1985. However, the rate of leaf fall was slower in 1985 with 42.8% and 52.5% falling in period 5 at the antenna and control sites respectively. By comparison, leaf fall was completed in period 4 in 1984.

Red maple appears to exhibit site differences in 1984, losing 76.7% of its leaves during periods 2 and 3 at the antenna site, while at the control 73.2% fall in period 4. These site differences are not as evident in 1985 although red maple retains its leaves longer at the control site than the antenna site. The heaviest red maple leaf fall occurred during period 4 at both sites.

Table 4.5. Percent of total leaf fall (by weight) for each sampling period by site, species, and year.

Collection Period	Northern Red Oak		Red Maple		Bigtooth Aspen		Birch/Hazelnut*	
	(Antenna Control)		(Antenna Control)		(Antenna Control)		(Antenna Control)	
	1984	1985	1984	1985	1984	1985	1984	1985
1	0.6	2.3	0.9	3.5	0.5	2.3	4.1	3.5
2	12.9	12.2	8.2	18.8	23.7	19.4	6.2	6.4
3	3.7	7.9	2.8	8.1	53.0	31.8	16.5	22.8
4	82.8	34.8	0.0	52.5	22.8	45.4	73.2	59.6
5	0.0	42.8	0.0	52.5	0.0	1.1	0.0	7.6

1 2 3 4 5	1984		1985	
	7/19 - 8/29	7/16 - 8/20	8/20 - 10/2	10/2 - 10/9
	8/29 - 10/3	10/2 - 10/9	10/9 - 10/16	10/16 - 10/23
	10/3 - 10/10	10/10 - 10/17		
	10/17 - 10/24			

\* Paper birch and beaked hazelnut leaves are indistinguishable after collection and therefore have been combined.

Similar site differences were found for bigtooth aspen in 1984; 84.2% fell during periods 2 and 3 at the antenna site, while 83.6% fell at the control site in periods 3 and 4. As with red maple, the site differences seen in 1984 are not as strongly expressed in 1985 although bigtooth aspen does retain its leaves somewhat longer at the control site.

Paper birch and beaked hazelnut leaves are indistinguishable after collection and therefore have been combined for this analysis. Heaviest leaf fall from these species in 1984 occurred during period 3 at the antenna site and during period 2 at the control site. However, in 1985 the period of heaviest leaf fall was period 3 at the antenna and period 4 at the control. Thus, the rate of leaf fall was reversed in 1985. Further site differences were shown by paper birch and hazelnut losing 84.4% during periods 2 and 3 at the antenna site while 82.4% during periods 3 and 4 at the control.

Climatic and stand conditions existing before and during the leaf fall period need to be examined as possible explanations for any statistically significant differences found in leaf fall for each species between 1984 and 1985. Soil factors will also be examined. This work will be conducted in 1986.

### Diameter Growth in Hardwood Species

#### Sampling and Data Collection

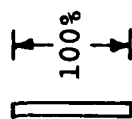
The onset and termination of cambial activity was determined from weekly readings of permanently installed dendrometer bands at both the antenna and control sites (See Element 3 - Tree Productivity). For each tree, the dendrometer band data was examined and the date recorded for the onset and termination of growth. Cambial activity was then expressed as the number of trees actively growing (in percent) for each weekly measurement and is shown in Figures 4.8 and 4.9. The onset of growth at the control for all species was not detected.

The vandalism that occurred at this site in 1984 required that the majority of dendrometer bands be replaced prior to the 1985 growing season. Following installation, a certain amount of slack will exist in the band. This slack is inherent to all bands and varies somewhat depending on stem diameter and bark characteristics. Therefore, the tree must grow enough to take up small amounts of slack in the band before growth can be detected. See Element 3: Tree Productivity for complete descriptions of methodologies used in correcting growth data for band slack. This correction factor is divided by the number of weeks required to eliminate the slack and then added to the reading for each of those weeks. Therefore, each tree that had a new band installed showed growth occurring during the first measurement period. Vandalism did not occur at the antenna site and, therefore, bands were not replaced and the observed readings in 1985 represent true growth. Correction factors were added to the 1984 growth data from the antenna and control sites by using an existing equation developed by Auchmoody (1976). The equations developed specifically for the antenna and control sites will also be applied to the 1984 data in the coming year and will be presented in the 1986 annual report.

# CAMBIAL ACTIVITY - Control Site

Percent of Trees Growing

1985



BIGTOOTH ASPEN

RED MAPLE

RED OAK

5/8 5/22 6/5 6/19 7/3 7/17 7/31 8/14 8/28 9/11 9/25 10/10

DATE

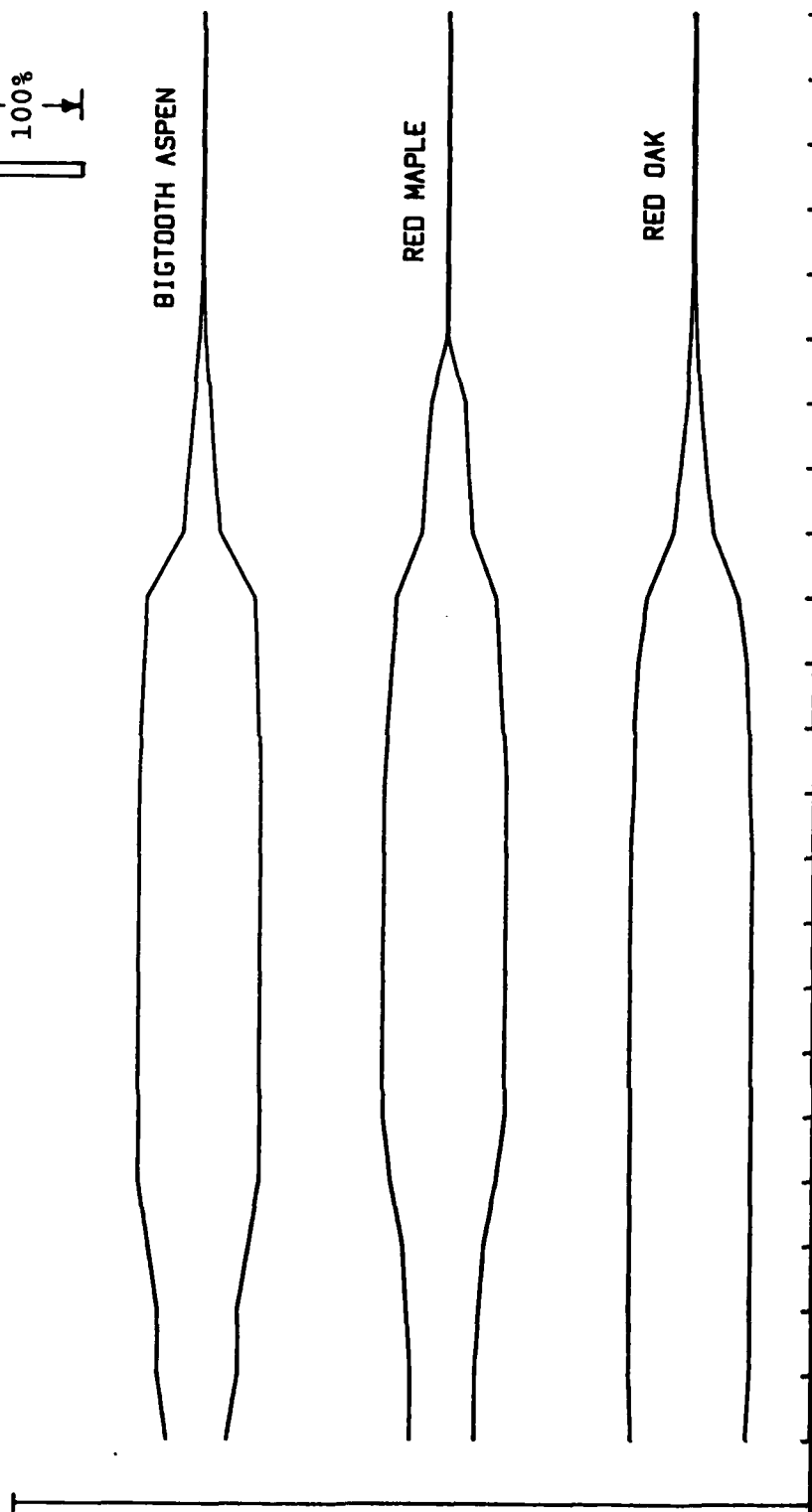
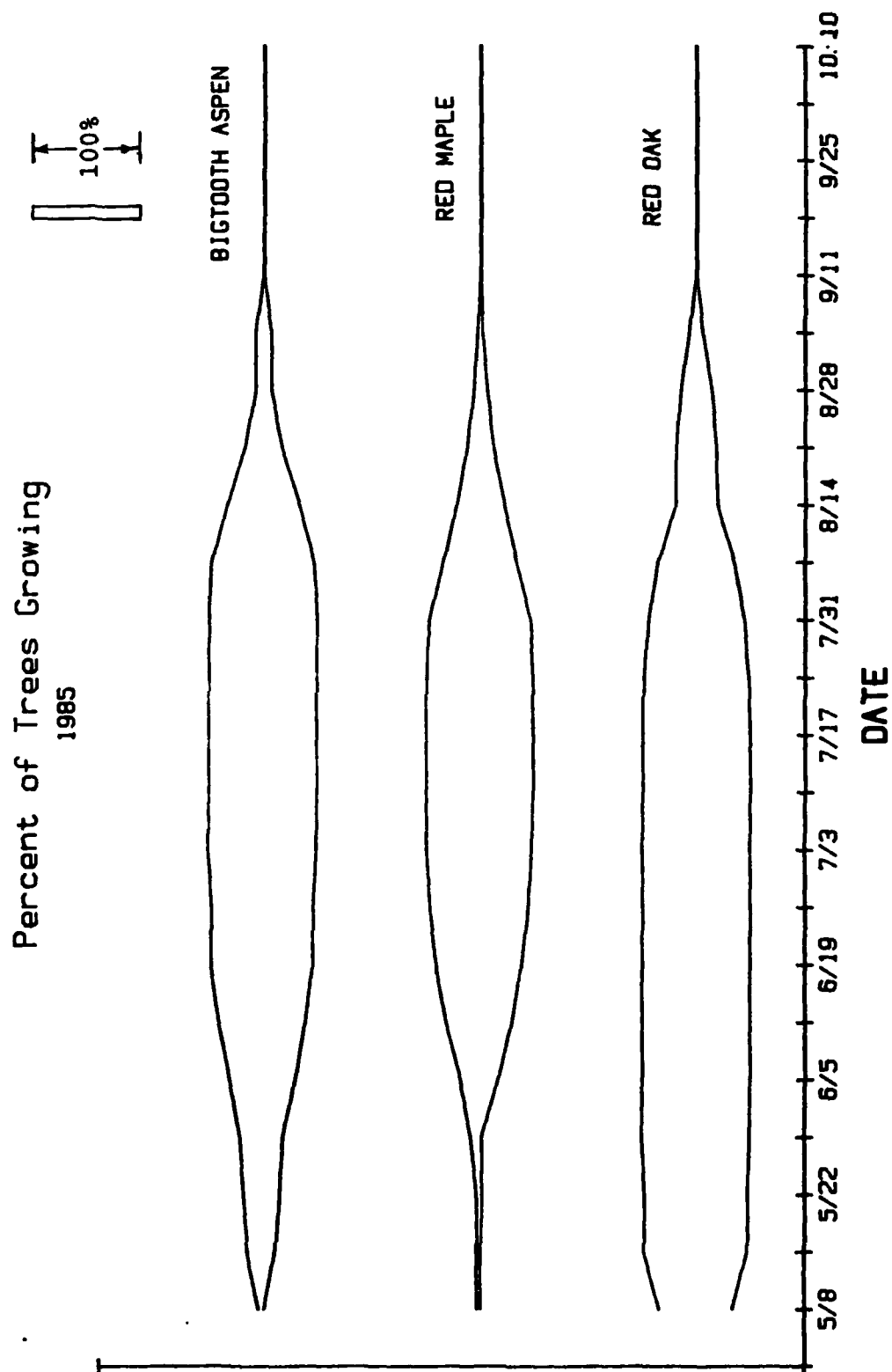


FIGURE 4.9 CAMBIAL ACTIVITY - Antenna Site



### Progress

Although the 1985 data at the antenna site represents true diameter growth, the majority of red oak were already growing at the end of the first measurement period (5/8). At this time, leaves have not emerged and the measurements reflect expansion of cells from water uptake. In light of this finding, measurements in 1986 will begin earlier in order to detect this swelling. Onset of growth was detected earlier for bigtooth aspen than for red maple at the antenna site. This pattern is also suggested in the data from the control site, but is masked by the application of the slack correction factor. The percentage of trees starting to grow increases slightly beginning on May 29 for red maple and bigtooth aspen at both the antenna and control sites. Termination of growth begins earliest for red maple compared with bigtooth aspen and red oak at the antenna site, but occurs at the same time for all species at the control. Growth on both sites by all species completely terminated by September 11.

Interpretation of these data is not complete without considering climatic conditions that exist prior to, during, and after the diameter growth period. Both air and soil temperature patterns appear to be related to the beginning and ending of cambial activity. Except for red oak, onset of growth occurs during a general warming trend in the spring that coincides with leaf out (Figure 2.4). The termination of growth for all species at both sites begins during a sharp decrease in temperature during the second week of August. These patterns are also reflected in soil temperature at 5 and 10 cm (Figures 2.17 and 2.18) although weekly changes are less dramatic than for air temperature. In addition, initial termination of growth coincides with the driest period of the growing season as indicated by soil moisture at 5 and 10 cm (Figures 2.26 and 2.27). Soil moisture reaches this

low level two weeks earlier at the antenna site compared with the control site and is reflected by a decrease in the number of red maple and red oak trees that are actively growing.

Analysis of the relationship between climatic weather variables and tree growth is discussed in Element 3 - Tree Productivity. Development of a growth model which includes weather variables is necessary to explain the conditions that result in the onset and termination of cambial activity. Calculation of growing degree days will be an important variable that will be considered in exploring these relationships.

#### HERBACEOUS PHENOLOGY

The herbaceous layer of a northern hardwood ecosystem is an ecologically important component of the system with respect to edaphic and vegetative factors. Phenology, the study of the timing of life cycle events relative to environmental cues (Barbour et al, 1980), has been used to quantitatively describe the herbaceous component of a northern hardwood forest (Mahall and Bormann, 1978). The onset of definable vegetative and reproductive phenophases characteristic of a herbaceous species will then be the primary response variables in assessing effects due to ELF fields.

The focus species of this study is Trientalis borealis L., starflower. Starflower is common and in sufficient numbers on the antenna and control sites and flowers more frequently than other forest floor species examined. The phenophases of starflower have also been well documented in northern Wisconsin by Anderson and Loucks (1973). Many herbaceous studies focusing on phenology revolve around the observation and measurement of vegetative and reproductive organs; thus, emphasis is given to quantitative observations of these organs on starflower in order to define characteristic phenophases with greater confidence. The null hypothesis to be tested overall is:



H<sub>0</sub>: There is no difference in the rate of leaf expansion and the onset of flowering of Trientalis borealis L. before and after the ELF antenna becomes operational.

Prior to a fully operational system, the rate of leaf expansion and the timing of flowering on each study site needs to be examined and compared to provide baseline information. The null hypotheses tested each year before the antenna becomes operational is:

H<sub>0</sub>: There is no difference in the rate of leaf expansion and the onset of flowering of Trientalis borealis L. between the antenna and control sites within a year.

### Sampling and Data Collection

To ensure an adequate representation of starflower phenophases, a minimum sample size of 200 individual plants per site was maintained at each observation period during leaf expansion, bud formation, and flowering. To achieve this goal, a single transect line was run and subsequently divided into permanent 1 meter square subplots. Individual plants within plots were numbered and tagged until the observation period when a normal distribution of individual stem lengths was attained. Stem length may be an indicator of the plant's potential sexual productivity. A normal distribution of stem length would aid in ensuring an adequate representation of the population. The number of meter square subplots required to attain a minimum sample size of 200 plants varied with each site and observation period. To reduce bias in choosing the 200th individual, all individuals were tagged in the subplot where the 200th individual was observed, hence the unequal sample size on any given day (Mahall and Bormann 1978). The sample size was maintained until tagged individuals began to die. Thereafter, observations were taken only on the remaining tagged individuals.

During the 1985 field season, data was collected during 21 observation periods on the antenna site and 20 observation periods on the control site beginning on May 11 and ending on August 29. Observations were most frequent between May 11 and June 13 (approximately every three days) so as to delineate leaf expansion, bud formation, and flowering periods with greater precision. Thereafter, observations were taken every seven days at each site. Parameters measured per plant during each observation period included stem length, number of leaves, length and width of the largest leaf, number of buds, number of flowers and fruit, and number of yellow and brown leaves.

### Progress

A normal distribution of individual stem length was attained on the antenna site by May 21. However, a normal distribution was not characteristic of individual stem lengths on the control. Rather, by May 15 the resulting distribution was skewed towards small plants and remained so over subsequent observation periods. Stem length did not appear to adversely affect the percent of flowers produced on either site (Figures 4.10 and 4.11). Flowering and fruit production was first observed on May 15 and 23, respectively at the control site (Table 4.6). The same phenophases were observed on May 21 and 29, respectively at the antenna site (Table 4.7). A difference of one week between the sites is apparent. Flowers remained on the plant longer at the antenna site than at the control. However, the onset of senescence was similar to both sites. Herbivory at the control was most pronounced with 4.2 plants missed per observation period, while 2.0 plants were missed per observation period at the antenna site.

Specific vegetative and reproductive phenophases, characteristic of starflower, have been selected for study. The rates of leaf expansion and flowering are the most readily defined events of starflower with distinct

STARFLOWER PHENOLOGY, 1985: ANTENNA

Plants within phenophase, %

Observation periods = 21

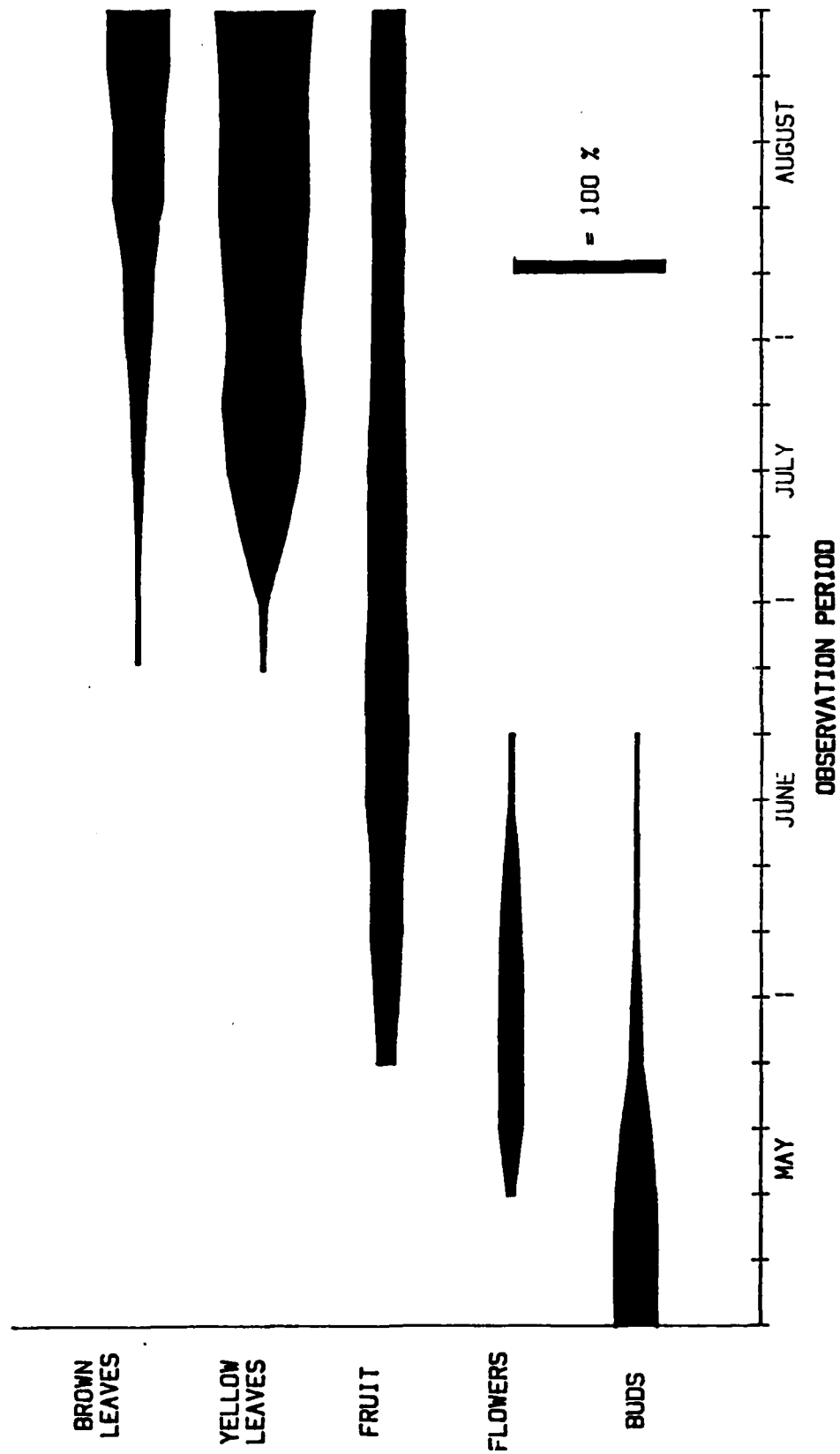


FIGURE 4.11

STARFLOWER PHENOLOGY, 1985: CONTROL

Plants within phenophase, %

Observation periods = 20

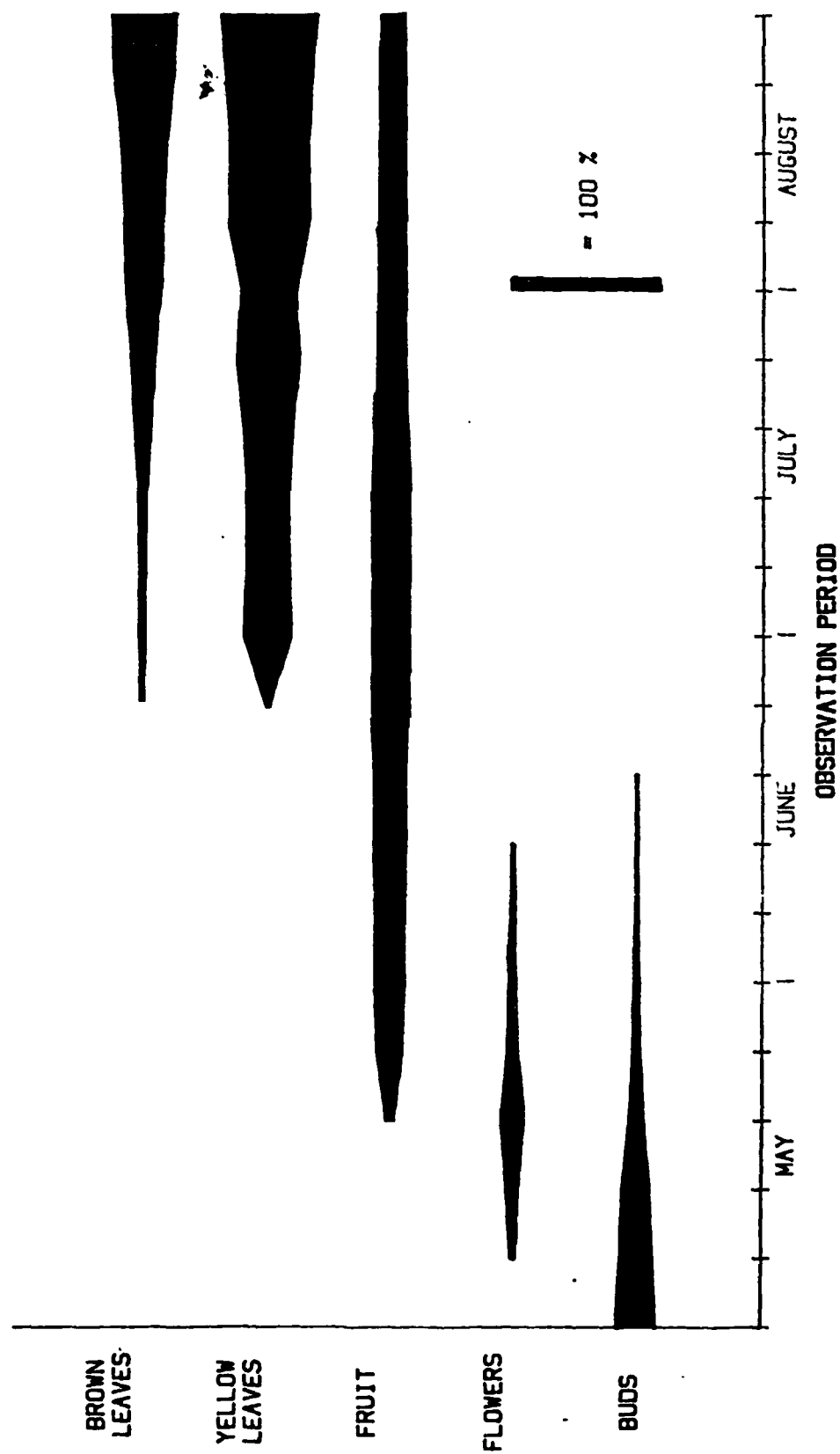


Table 4.6. Plants within each phenophase (%) on the control site for the 1985 field season.

Observation Period		Buds	Flowers	Fruit	Yellow Leaves	Brown Leaves
May	11	31.0				
	15	24.5	3.1			
	20	20.4	9.3			
	23	9.9	18.4	4.9		
	28	4.1	7.2	20.3		
	30	3.1	3.6	24.1		
June	4	0.9	2.7	24.6		
	8		0.4	26.9		
	11	0.5		25.9		
	18			30.2	2.0	2.0
	25			29.6	37.9	4.9
July	2			31.0	33.5	5.0
	9			31.1	33.2	6.8
	16			26.0	39.2	13.8
	23			21.5	50.6	19.8
	30			19.5	43.0	29.7
Aug	6			20.8	64.6	31.9
	13			19.5	62.2	37.0
	20			20.3	68.4	48.7
	27			17.9	77.7	52.4

Table 4.7. Plants within each phenophase (%) on the antenna site for the 1985 field season.

Observation Period		Buds	Flowers	Fruit	Yellow Leaves	Brown Leaves
May	11	33.9				
	14	34.6				
	21	30.9	4.9			
	24	22.3	17.9			
	29	8.4	18.3	11.9		
	31	5.9	17.8	18.8		
June	3	1.0	14.9	24.9		
	6	2.0	9.9	24.7		0.5
	10		1.4	32.1		
	13	0.5	1.6	33.2		
	20			32.2	1.0	1.5
	27			27.3	5.1	0.5
July	3			29.5	34.1	3.4
	11			27.7	56.2	8.2
	18			25.4	66.0	12.9
	25			22.8	56.6	21.5
Aug	1			22.2	64.7	24.3
	8			23.3	71.5	39.7
	15			25.0	69.2	38.4
	22			26.4	70.3	50.0
	29			22.8	78.0	49.6

beginning and ending points as well as occurring early in the growing season, minimizing the effects of herbivory and disease. A simple linear regression equation relating leaf length and leaf width to actual leaf area will be developed to determine the rate of leaf expansion. Observational data collected on flowering will define the flowering phenophase characteristic of the site and the climatic conditions during a given growing season.

Flowering appears to be a function of 95% leaf expansion as well as air temperature (Anderson and Loucks, 1973), where leaf expansion appears to be a function of air temperature and photoperiod. Available soil water or soil moisture may also be strongly correlated with leaf expansion. Graphical representations and correlation matrices of these relationships need to be examined to determine whether a linear or nonlinear relationship exists between these variables.

Flowering may not occur on each plant each year. Approximately 15% to 20% of the plants on each study site flowered this season. In the event that flower production is so low in a given field season that comparisons are invalid, only the rate of leaf expansion will be examined.

Testing for variation in the timing of the phenological events will incorporate regression analysis. Mathematical models predicting the rate of 95% leaf expansion and the subsequent onset of flowering will be developed for each site. Data will be used from this field season and all future years prior to an operational antenna to cover as wide a range in climatological conditions as possible. Comparisons will be made between coefficients estimated from each model for possible site differences.

## ELEMENT 5: HERBACEOUS VEGETATION COVER

The overall objectives of this element are 1) to collect and evaluate data on the frequency and coverage of herbaceous plants on selected plots within the ELF antenna prior to the operation of the antenna, and 2) use this baseline data to evaluate the possible effects of ELF electromagnetic fields on the diversity, frequency, and coverage of herbaceous plants. Since the composition of the herbaceous plant community has been known to be influenced by environmental changes, ELF fields may cause changes in the diversity and abundance of herbaceous plant species. An ELF effect could be reflected by a change in:

- 1) number of species present,
- 2) species composition, and
- 3) the relative importance of individual species.

Trends in species composition over time will be detected by monitoring the previously stated variables on a yearly basis. Comparisons of each stand type will be made between the antenna and control sites. Although differences exist in vegetative structure between these sites, the magnitude of these differences will be monitored as one indicator of possible ELF effects.

### Sampling and Data Collection

A modification of the sampling method was made in 1985 to further document percent cover and frequency. In the past, a line intercept method was used to estimate percent cover. This method did not provide an adequate measure of frequency which is needed to calculate importance values. Thus, in 1985, percent cover and frequency were obtained by randomly placing four 1 M<sup>2</sup> subplots along 3 permanently marked transects within each plot on the



herbaceous plant reserves (total = 36). Similarly, 24 subplots were randomly located on permanently marked transects on the red pine plantations. At the antenna and control sites, percent cover of each species occurring on each subplot was recorded. Field work was conducted in August when species diversity and plant biomass are greatest. Relative cover, relative frequency, and importance values for each species were calculated as follows:

$$\text{Relative cover (\%)} = \frac{\text{Percent cover of species A}}{\text{Total cover}} \times 100$$

$$\text{Relative frequency (\%)} = \frac{\text{\# of subplots species A present in}}{\text{Total \# of subplots}} \times 100$$

$$\text{Importance value} = \text{Relative frequency} + \text{relative cover}$$

### Progress

#### Herbaceous Reserve

Species comprising 90% relative cover on the herbaceous reserves along with associated importance values are listed in Table 5.1. Importance values could not be calculated for the 1984 data due to the inadequacy of the sampling method. Additionally, relative cover is presented for 1985 only as a means of comparison with 1984. Future yearly comparisons will use only importance values because they include both relative cover and frequency.

At the antenna site eight species comprised 90% of the relative cover in both 1984 and 1985. At the control site nine species were found in 1984 and eleven in 1985. Different species comprise this value between years on both sites and is probably due to the difference in sampling methods.

Pteridium aquilinum is the most abundant species on both sites in both 1984 and 1985; however, its dominance decreases in 1985. The dominance of many other species common to both years also decreased. In most cases a

Table 5.1. Species comprising 90% relative cover, and their associated importance values, present on herbaceous plant reserves.

<u>Species</u>	<u>Importance Value</u>		<u>% Relative Cover</u>	
	<u>Antenna site</u> 1985	<u>Control site</u> 1985	<u>Antenna site</u> 1985 1984	<u>Control site</u> 1985 1984
<u>Pteridium aquilinum</u>	101.6	102.3	40.5	59.5
<u>Gaultheria procumbens</u>	99.6	-	10.7	5.9
<u>Aster macrophyllus</u>	51.5	78.2	4.2	4.2
<u>Rubus allegheniensis</u>	41.6	30.1	8.3	2.6
<u>Vaccinium membranaceum</u>	40.5	-	10.0	4.2
<u>Trientalis borealis</u>	23.7	90.9	1.5	-
<u>Rubus parviflorus</u>	13.6	-	8.1	4.0
<u>Crataegus spp.</u>	12.8	-	7.3	-
<u>Viburnum acerifolium</u>	-	28.3	-	-
<u>Oryzopsis asperifolia</u>	-	67.0	-	-
<u>Aralia nudicaulis</u>	-	38.1	-	-
<u>Maianthemum canadense</u>	-	57.3	-	-
<u>Anemone quinquefolia</u>	-	56.9	-	1.7
<u>Lycopodium obscurum</u>	-	39.0	-	-
<u>Rubus idaeus</u>	-	19.0	-	-
<u>Lycopodium clavatum</u>	-	-	-	1.7
<u>Waldesteinia fragarioides</u>	-	-	-	-

large portion of the changes can be explained by the difference in sampling method.

Species composition in 1984 and 1985 showed differences between sites. Of the species that comprise 90% of the relative cover in 1985, only Pteridium aquilinum, Aster macrophyllus, Rubus alleghenienses, and Trientalis borealis are common to both the antenna and control sites. Ranking of these species (importance value) is similar on both sites except for Trientalis borealis which is second in importance at the control site. In 1984, Gaultheria procumbens and Vaccinium membranaceum were also found to be common to the sites but Trientalis borealis was not. These differences may be partially explained by the difference in sampling methods.

#### Red Pine Plantations

Measurements of plant cover were not made on the plantation plots in 1984. These sites were cleared in June 1984 and the herbaceous community was severely disturbed during the felling and skidding operations. For the remainder of the growing season the herbaceous component did little in terms of recovery, consisting mostly of damaged individuals that survived the disturbance. Although a small amount of resprouting occurred, it was decided that this situation would not provide a good baseline from which to follow successional trends. Therefore, the first measurement of the red pine plantations was made in 1985. Importance values for the ten most important species on the red pine plantations in 1985 are shown in Table 5.2. Relative cover values are not shown here because they were used only to compare 1984 with 1985 on the herbaceous reserves.

Six species are common to both sites. Pteridium aquilinum was the most important species at the antenna site. Aster macrophyllus was most

Table 5.2. Ten most important species on the antenna and control plantation sites respectively.

<u>Species</u>	<u>Importance Value</u>	
	<u>Antenna site</u> <u>1985</u>	<u>Control site</u> <u>1985</u>
<u>Pteridium aquilinum</u>	115.1	116.0
<u>Carex umbellata</u>	73.8	41.4
<u>Gautheria procumbens</u>	70.8	-
<u>Diervilla lonicera</u>	61.6	-
<u>Oryzopsis asperifolia</u>	57.6	48.4
<u>Crataegus spp.</u>	56.9	44.2
<u>Vaccinium membranaceum</u>	45.6	30.9
<u>Rubus allegheniensis</u>	33.0	77.3
<u>Rubus parviflorus</u>	28.7	-
<u>Panicum implicatum</u>	28.4	-
<u>Lycopodium obscurum</u>	-	38.4
<u>Aster macrophyllus</u>	-	126.8
<u>Waldesteinia fragarioides</u>	-	63.3
<u>Maianthemum canadense</u>	-	47.5

important followed by Pteridium aquilinum at the control. By contrast, Aster macrophyllus at the antenna site was not represented well enough to rank high in the importance value table. All common species are ranked differently between sites with the exception of Oryzopsis asperifolia which ranked fourth on both sites.

As would be expected, the presence/absence or importance of individual species would change following a disturbance such as timber harvesting. Comparison of Tables 5.1 and 5.2 show this change in species composition. For example, Trientalis borealis which is well represented on the herbaceous reserve plots, does not appear among the species which are listed for the plantations. In addition, we are beginning to see the presence of invading species such as Cirsium vulgare, Verbascum thapsus, Taraxacum officinale, and Hieracium aurantiacum on the plantations. Annual monitoring of the successional process on the plantations will allow us to identify invading species with respect to number, composition, and relative importance.

#### Future Considerations

Measurement of the herbaceous community will continue in 1986 on both the herbaceous reserve plots and red pine plantations. Data will be used to document species composition and changes in presence/absence or importance of individual species. The trends that are identified will help to further characterize the study sites in light of the differences between sites described in Element 1: Plot Selection. Compositional trends will be monitored following activation of the ELF system which will allow detection of possible changes in the herbaceous community due to ELF. Ambient monitoring data will be evaluated along with the vegetation data to help explain yearly variation in species importance. Explaining yearly trends

with respect to the environment will be difficult on the red pine plantations because of the dynamic nature of this young community. Therefore most of our efforts will be concentrated on the herbaceous reserves where the plant community is more stable and thus more likely to express possible effects of ELF electromagnetic fields.

#### ELEMENT 6. POPULATION DYNAMICS OF MYCORRHIZAL MACROFUNGII VIA SPOROCARP PRODUCTION

The mixed hardwood forest was originally selected for study because 1) it represents a large proportion of the forest area transected by the ELF antenna system, and 2) it contains a substantial component of ectomycorrhizal tree species. Ectomycorrhizae lend themselves to more straightforward study than do endomycorrhizae because 1) many ectomycorrhizal fungi produce large, often showy, fruiting bodies (sporocarps), 2) many of these fungi can be grown in pure culture on artificial media, and 3) ectomycorrhizal fine root infections can be characterized and quantified at low magnification. The same cannot be said for endomycorrhizae, and most tree species are associated predominantly with either ecto- or endomycorrhizal fungi.

Mycorrhizae are essential to healthy plant growth because they serve as the integrating bridge between plant root systems and the surrounding soil. As such, mycorrhizae are an obvious object of study in the evaluation of possible ecosystem perturbations (e.g. Tyler 1985, 1984; Reich et al. 1985).

Because the mycorrhizal relationship is a mutualistic one, mycorrhizae are sensitive indicators of effects on either the host or the obligately parasitic mycorrhizal fungus, or both. Evidence suggesting treatment effects on one component of the relationship can be weighed against possible effects on the other component. Finally, recent studies demonstrating the existence of naturally produced transcellular electrical fields in fungi suggest a possible avenue by which artificially produced electrical fields (e.g. ELF fields) might interfere with healthy mycorrhizal fungus growth and reproduction (Gow 1984, Harold et al. 1985; Kropf et al. 1985).

Detailed study of root growth and associated mycorrhizal infection dynamics has been directed at the three red pine study plantations, because

of 1) the interest in studying red pine regeneration as part of the ELF environmental monitoring program, 2) the considerable background knowledge existing on red pine growth and mycorrhizae, and 3) the relative ease of studying red pine seedling root systems as opposed to those of mature hardwoods. See the following chapter (Element 7 - Mycorrhizal Characterization and Root Growth) for details on these mycorrhizal studies.

Nevertheless, the mixed hardwood pole-stands at the antenna and control sites offer an excellent opportunity to describe and quantify the indigenous ectomycorrhizal fungus community via the population dynamics of sporocarp production. Sporocarp production represents an investment of fungal energy obtained from the host toward the perpetuation of the fungal species. As such, the extent of sporocarp production reflects the combined vigor of the host-parasite system. Biologically meaningful environmental impacts on either the host or parasite populations should result in altered fruiting patterns by the mycorrhizal fungi present in the stand. Consequently, the main objective of this work element is to characterize the relative vigor of the indigenous ectomycorrhizal macrofungal community via fruiting dynamics of major component species. A secondary objective is to round out the reference collections of cultures and freeze-dried sporocarps representative of the ectomycorrhizal fungus communities at the Antenna and Control sites.

#### Sampling and Data Collection

The population dynamics of ectomycorrhizal macrofungi in the mixed hardwood study pole stands are being evaluated through periodic non-destructive monitoring of sporocarp production on two sets of three contiguous 30 m x 35 m herbaceous reserve plots located at the antenna and control sites. Each plot was subdivided into 4 strips 7.5 m wide to facilitate survey. Tallied sporocarps were slit vertically through the



pileus in situ with a sharp knife so that they would not be re-recorded during subsequent visits. In general, tallied specimens were left on the plots 1) to sporulate, and 2) in order to avoid artifactual impact on the next flush (Manachere 1985). The slit pileus was often the only mark of the survey. Sporocarps were only picked as necessary for identification or reference. The large size of each study plot minimizes the variability among sporocarp counts between years by absorbing the effect of spatial redistribution of sporocarp production around host trees between years. Sporocarp production is closely tied to host photosynthetic activity (Last et al. 1984), and host genotype (Last et al. 1984, Mason et al. 1984), and can be expected to proceed as regularly as the relatively stable study stands and climate will permit.

Because local microclimate and host tree species (or genotype) distributions vary slightly between the study plots in each stand, it is not surprising to find substantial differences in the representation of mycorrhizal fungus species among contiguous plots. This is viewed as evidence of the sensitivity of these fungi to their immediate environs. As a result, quantitative study of sporocarp production dynamics must focus on 1) explanation of patterns of annual fluctuation in fruiting abundance, and 2) comparison between years of the relative abundance of sporocarp production among the study plots at each site. Clearly, individual fungus species need not be uniformly distributed over the study plots or sites in order to contribute meaningfully to evaluation of environmental perturbation. It is much more important to identify the relationships between fruiting and ambient climatic variables so that annual fluctuations in fruiting at the sites can be properly interpreted.

Factors which regulate sporocarp production include light, temperature and fungal nutrition (Manachere, 1985). Reduced light intensity or

shortened daylength are known to affect fruiting. Reduced temperature can also stimulate sporocarp maturation. Sporocarp primordia of some fungi form only when mycelial growth slows in association with carbohydrate depletion in the growth medium. Sporocarp development then becomes dependent on the nutrient reserves of the mycelium. Also, the availability of water as precipitation probably affects fruiting abundance, considering the high moisture content of sporocarps.

These environmental relationships help to explain why the preponderance of mycorrhizal fruiting in the study stands takes place between August and early October. Patterns of distribution for air and soil temperature, solar radiation, total precipitation and frequency of precipitation events are currently being evaluated for 1985 in light of sporocarp survey results. Timing of litterfall and stem diameter growth are also being considered, as factors related to host metabolic activity. If fruiting is tied to carbohydrate supply, mycorrhizal fruiting could be partially explained by events leading to host dormancy in the autumn since mycorrhizal fungi are heavily dependent on their hosts for energy (Gadgil and Gadgil, 1971).

Survey activity began in 1985 shortly after reports of fruiting were received from the field crew. Thereafter, study plots were carefully surveyed on a weekly to biweekly basis (six visits) between August 20 and October 13. Visits terminated with cessation of fruiting, which has coincided in both 1984 and 1985 with the end of litterfall. During visits, the forest floor is left as undisturbed as possible; no doubt many sporocarps of smaller stature or developing between visits are missed. To help account for these factors, 292 individual specimen sporocarps representing 33 fungus species were flagged in the field during 1985 in order to determine their longevity as a further aid to interpretation of sporocarp counts between years. During 1984, 343 specimens were likewise

flagged for determination of longevity. These data help to identify those species for which weekly or bi-weekly surveys will most precisely characterize sporocarp population dynamics. Species for which sporocarps do not often survive for one week must be markedly under-represented and would have to be relatively prolific producers of sporocarps in order to provide useful data.

Annual counts are used to determine 1) dates of earliest and latest record, 2) dates by which 50 percent of the year's total fruiting had occurred, and 3) date(s) of peak fruiting for each of 33 ectomycorrhizal fungi. Techniques for characterizing and comparing fungal populations via fruiting body production have been published (Grainger 1946, Parker-Rhodes 1951, Hering 1966, Richardson 1970, Fogel 1976, Fogel 1981). Other quantitative concepts which may prove useful in comparing data sets include coefficient of community (Pielou 1977), and Orloci's sums of squares method based on standardized distances (Orloci 1967). Work is underway to determine the most useful tests of population parameters.

### Progress

Table 6.1 presents a summary of the 1985 survey results by site. Fruiting peaked in mid-September for nearly all study species and on both the antenna and control sites. Fruiting in 1984 peaked slightly later in September (1984 Report, p.79). Weighted midpoints coincide closely with peak dates for both sites during both years. None of the species selected for study had population peaks coinciding with the first or last dates of survey. Unfortunately, weather differences between 1984 and 1985 can not be explored. Nevertheless, possible connections with 1985 weather and host growth variables are currently being evaluated. Table 6.2 presents total counts by site recorded in 1984 and 1985. Table 6.3 presents the same counts by plots within sites. The consistency between years in

representation of fungal species within the plots at each site is very evident. Table 6.4 presents data on the longevity of sporocarps flagged in 1984 and 1985. Differences in longevity between years (due to foraging by rodents, etc.) will help to determine the relative efficiencies of survey data from different years.

Table 6.1 Seasonal distribution of fruiting by ectomycorrhizal fungi on the three 35 m x 30 m herbaceous reserve plots at the antenna and control study sites between 20 August and 13 October, 1985.

Family	Genus	Species	Earliest Record		Latest Record		Weighted Midpoint		Mode	
			Antenna	Control	Antenna	Control	Antenna	Control	Antenna	Control
Amanitaceae	<u>Amanita</u>	<u>Bisporigera</u>	20 Aug.	27 Aug.	18 Sept.	13 Oct.	4 Sept.	11 Sept.	4 Sept.	11 Sept.
		<u>brunnescens</u>	20 Aug.	4 Sept.	13 Oct.	13 Oct.	18 Sept.	18 Sept.	18 Sept.	18 Sept.
		<u>Citrina</u>	20 Aug.	11 Sept.	18 Sept.	11 Sept.	27 Aug.	11 Sept.	27 Aug.	11 Sept.
		<u>muscaria</u>	20 Aug.	4 Sept.	11 Sept.	11 Sept.	11 Sept.	11 Sept.	11 Sept.	11 Sept.
		<u>Tulva</u>	18 Sept.	20 Aug.	18 Sept.	18 Sept.	18 Sept.	27 Sept.	18 Sept.	27 Sept.
Boletaceae	<u>Boletellus</u>	<u>ruscellii</u>	20 Aug.	27 Aug.	27 Aug.	27 Aug.	27 Aug.	27 Aug.	27 Aug.	27 Aug.
		<u>piperatus</u>	20 Aug.	27 Aug.	11 Sept.	27 Aug.	27 Aug.	27 Aug.	27 Aug.	27 Aug.
		<u>leccinum</u>	27 Aug.	20 Aug.	18 Sept.	18 Sept.	11 Sept.	11 Sept.	11 Sept.	18 Sept.
		<u>Cantharellus</u>	27 Aug.	27 Aug.	13 Oct.	13 Oct.	11 Sept.	11 Sept.	11 Sept.	11 Sept.
		<u>Cortinarius</u>	27 Aug.	27 Aug.	13 Oct.	13 Oct.	11 Sept.	11 Sept.	11 Sept.	11 Sept.
Cantharellaceae	<u>Cantharellus</u>	<u>albobolaceus</u>	27 Aug.	4 Sept.	13 Oct.	13 Oct.	11 Sept.	11 Sept.	11 Sept.	11 Sept.
		<u>armillatus</u>	27 Aug.	20 Aug.	13 Oct.	13 Oct.	11 Sept.	11 Sept.	11 Sept.	11 Sept.
		<u>Flavifolius</u>	27 Aug.	27 Aug.	13 Sept.	13 Sept.	11 Sept.	11 Sept.	11 Sept.	11 Sept.
		<u>Semisanquineus</u>	27 Aug.	4 Sept.	11 Sept.	11 Sept.	11 Sept.	11 Sept.	11 Sept.	11 Sept.
		<u>Sponaerosporus</u>	27 Aug.	4 Sept.	18 Sept.	4 Sept.	11 Sept.	11 Sept.	11 Sept.	4 Sept.
Elaphomyces	<u>Elaphomyces</u>	<u>granulatus</u>	27 Aug.	27 Aug.	13 Oct.	13 Oct.	11 Sept.	11 Sept.	11 Sept.	11 Sept.
		<u>repandum</u>	27 Aug.	4 Sept.	18 Sept.	18 Sept.	11 Sept.	11 Sept.	11 Sept.	11 Sept.
		<u>zonatum</u>	20 Aug.	20 Aug.	18 Sept.	18 Sept.	11 Sept.	11 Sept.	11 Sept.	11 Sept.
		<u>argillifolius</u>	20 Aug.	20 Aug.	18 Sept.	18 Sept.	4 Sept.	4 Sept.	4 Sept.	11 Sept.
		<u>Rufus</u>	20 Aug.	20 Aug.	18 Sept.	18 Sept.	4 Sept.	4 Sept.	11 Sept.	11 Sept.
Russulaceae	<u>Russula</u>	<u>subvillereus</u>	11 Sept.	27 Aug.	13 Oct.	18 Sept.	11 Sept.	11 Sept.	11 Sept.	11 Sept.
		<u>lorminosus</u>	11 Sept.	4 Sept.	13 Oct.	13 Oct.	11 Sept.	11 Sept.	11 Sept.	11 Sept.
		<u>emetica</u>	20 Aug.	20 Aug.	13 Oct.	13 Oct.	11 Sept.	11 Sept.	11 Sept.	11 Sept.
		<u>Fragilis</u>	20 Aug.	20 Aug.	18 Sept.	13 Oct.	11 Sept.	11 Sept.	11 Sept.	4 Sept.
		<u>Taurocera</u>	20 Aug.	20 Aug.	18 Sept.	18 Sept.	4 Sept.	4 Sept.	4 Sept.	11 Sept.
Tricholomataceae	<u>Laccaria</u>	<u>variata</u>	20 Aug.	20 Aug.	18 Sept.	18 Sept.	4 Sept.	4 Sept.	4 Sept.	11 Sept.
		<u>Laccata</u>	20 Aug.	20 Aug.	13 Oct.	13 Oct.	11 Sept.	11 Sept.	11 Sept.	11 Sept.
		<u>Flavivirens</u>	4 Sept.	11 Sept.	13 Oct.	13 Oct.	11 Sept.	11 Sept.	11 Sept.	11 Sept.
		<u>resplendens</u>	11 Sept.	11 Sept.	11 Sept.	18 Sept.	11 Sept.	11 Sept.	11 Sept.	11 Sept.
		<u>Tricholoma</u>	11 Sept.	11 Sept.	11 Sept.	18 Sept.	11 Sept.	11 Sept.	11 Sept.	11 Sept.

- a. Presence detected by association with fruiting of *Cordyceps* spp.  
b. Date by which 50 percent of the season's fruiting had taken place.  
c. Date of most abundant fruiting.  
d. The mode is shared by more than 1 date.

Table 6.2. Total numbers of sporocarp observations recorded in 1984 and 1985 for 33 presumed ectomycorrhizal macrofungi on three 30 m x 35 m herbaceous reserve plots located at the Antenna and Control study sites. Six sets of observations were made in each year (between 4 August and 13 October in 1984, and between 20 August and 13 October in 1985).

Family	Genus	Species	Total Number of Records			
			Antenna		Control	
			1984	1985	1984	1985
Amanitaceae	<u>Amanita</u>	<u>bisporigera</u>	22	7	2	--
		<u>brunnescens</u>	40	17	22	15
		<u>citrina</u>	18	7	8	7
		<u>muscaria</u>	52	114	--	3
		<u>fulva</u>	--	--	7	12
Boletaceae	<u>Amanitopsis</u>	<u>vaiginata</u>	3	1	27	7
		<u>russellii</u>	--	--	12	1
		<u>piperatus</u>	17	30	1	1
		<u>leccinum</u>	4	11	29	31
		<u>cantharellus</u>	--	--	99	74
Cantharellaceae	<u>Cantharellus</u>	<u>lutescens</u>	148	223	102	183
		<u>alboviolaceus</u>	16	9	49	81
		<u>armillatus</u>	15	2	13	3
		<u>flavifolius</u>	10	21	7	2
		<u>semisanguineus</u>	95	84	5	1
Elaphomycetaceae	<u>Rozites</u>	<u>spiraerosporus</u>	105	272	44	29
		<u>trivialis</u>	47	132	79	93
		<u>capitata</u>	32	59	12	6
		<u>granulatus</u>	--	--	28	8
		<u>repandum</u>	--	--	11	2
Hydnaceae	<u>Elaphomyces</u>	<u>zonatum</u>	108	41	12	48
		<u>argillaceifolius</u>	898	59	76	29
		<u>rufus</u>	7	--	49	11
		<u>subvillereus</u>	6	16	30	49
		<u>torminosus</u>	2	1	41	39
Russulaceae	<u>Russula</u>	<u>brevipes</u>	171	351	126	18
		<u>emetica</u>	26	29	24	44
		<u>fragilis</u>	18	7	52	3
		<u>taurocerasi</u>	17	63	13	61
		<u>paludosa</u>	145	66	336	93
Tricholomataceae	<u>Laccaria</u>	<u>variata</u>	103	74	85	101
		<u>laccata</u>	16	36	--	7
		<u>flavovirens</u>	3	6	16	13
		<u>resplendens</u>	--	--	--	--
		<u>tricholoma</u>	--	--	--	--

A. Because of the clumped distribution and small size of individual sporocarps, clumps rather than individuals were tallied.

B. In 1984, individual sporocarps of L. rufus were tallied at first.

Table 6.3. Distribution of sporocarp observations recorded in 1984 and 1985 for 33 presumed ectomycorrhizal macrofungi on three 30 m x 35 m herbaceous reserve plots located at the Antenna and Control study sites. Six sets of observations were made in each year (between 4 August and 13 October in 1984, and between 20 August and 13 October in 1985).

Family	Genus	Species	TOTAL COUNTS					
			Plot 1		Antenna Site		Plot 3	
			1984	1985	1984	1985	1984	1985
Amanitaceae	<u>Amanita</u>	<u>bisporigera</u>	7	0	15	6	1	1
		<u>brunnescens</u>	1	1	9	8	30	8
		<u>citrina</u>	9	2	6	1	9	4
		<u>muscaria</u>	13	25	33	80	7	9
		<u>fulva</u>	0	0	0	0	0	0
Boletaceae	<u>Amanitopsis</u>	<u>vaginata</u>	1	0	1	1	1	0
		<u>russellii</u>	0	0	0	0	0	0
		<u>piperatus</u>	4	6	9	22	4	2
		<u>scabrum</u>	5	4	1	3	0	4
		<u>lutescens (a)</u>	0	0	0	0	0	0
Cantharellaceae	<u>Cantharellus</u>	<u>albobovioleus</u>	52	69	114	149	1	5
		<u>armillatus</u>	5	4	4	5	5	0
		<u>flavifolius</u>	7	1	0	0	9	1
		<u>semisanguineus</u>	5	7	5	13	0	1
		<u>sonaerosporus</u>	55	28	52	50	0	5
Elaphomycetaceae	<u>Rozites</u>	<u>trivialis</u>	79	131	63	135	0	6
		<u>capitata</u>	39	70	28	62	0	0
		<u>granulatus (c)</u>	24	21	12	24	11	14
		<u>repandum</u>	0	0	0	0	0	0
		<u>zonatum</u>	0	0	0	0	0	0
Hydnaceae	<u>Hydnum</u>	<u>argillaceifolius</u>	28	6	31	12	51	23
		<u>rufus (ab)</u>	34	7	484	5	382	46
		<u>subvelutereus</u>	7	0	0	0	0	0
		<u>tormentosus</u>	5	7	1	2	0	7
		<u>brevipes</u>	1	1	0	0	1	0
Russulaceae	<u>Russula</u>	<u>emetica</u>	96	186	58	112	21	53
		<u>fragilis</u>	18	20	10	9	0	0
		<u>laurocerasus</u>	7	2	9	3	3	2
		<u>paludosa</u>	4	16	7	36	6	11
		<u>variata</u>	59	33	35	13	51	20
Tricholomataceae	<u>Laccaria</u>	<u>laccata</u>	24	25	26	17	53	32
		<u>flavovirens</u>	3	10	15	26	1	0
		<u>resplendens</u>	3	3	0	3	0	0
		<u>tricholoma</u>						

(a) Because of the clumped distribution and small size of individual sporocarps, clumps rather than individuals were tallied.

(b) In 1984, individual sporocarps of L. rufus were tallied at first.

(c) Presence detected via fruiting of Cordyceps spp.

Table 6.3. Distribution of sporocarp observations recorded in 1984 and 1985 for 33 presumed ectomycorrhizal macrofungi on three 30 m x 35 m herbaceous reserve plots located at the Antenna and Control study sites. Six sets of observations were made in each year (between 4 August and 13 October in 1984, and between 20 August and 13 October in 1985).

Family	Genus	Species	TOTAL COUNTS					
			Plot 1		Control Site		Plot 3	
			1984	1985	1984	1985	1984	1985
Amanitaceae	<u>Amanita</u>	<u>bisporigera</u>	1	0	1	0	0	0
		<u>brunnescens</u>	1	1	4	8	17	6
		<u>citrina</u>	1	0	3	2	4	5
		<u>muscaria</u>	0	2	0	1	0	0
Boletaceae	<u>Amanitopsis</u>	<u>fulva</u>	1	5	5	7	1	1
		<u>vaginata</u>	13	3	5	2	2	2
		<u>russellii</u>	12	1	0	0	0	0
		<u>piperatus</u>	0	0	0	0	1	1
Cantharellaceae	<u>Boletus</u>	<u>scabrum</u>	4	6	16	20	0	5
		<u>lutescens (a)</u>	35	31	20	8	44	35
		<u>albopilaeus</u>	4	14	32	51	66	118
		<u>armillatus</u>	4	8	35	64	1	9
Cortinariaceae	<u>Cortinarius</u>	<u>flavifolius</u>	1	3	1	3	11	2
		<u>semisanguineus</u>	5	2	0	0	2	0
		<u>sonaeosporus</u>	0	0	0	1	5	0
		<u>trivialis</u>	4	7	29	17	11	15
Elaphomycetaceae	<u>Rozites</u>	<u>caperata</u>	2	2	55	63	22	28
		<u>granulatus (c)</u>	2	0	3	3	7	3
		<u>repandum</u>	1	1	5	4	19	1
		<u>zonatum</u>	11	2	0	0	0	0
Hydnaceae	<u>Hydnellum</u>	<u>agillaceifolius</u>	4	20	6	17	2	11
		<u>rufus (ab)</u>	1	5	70	17	5	7
		<u>subvelutius</u>	9	2	14	8	26	1
		<u>tominosus</u>	3	14	22	33	5	2
Russulaceae	<u>Russula</u>	<u>brevipes</u>	24	27	4	4	13	8
		<u>emetica</u>	13	3	45	9	68	6
		<u>fragilis</u>	7	10	12	23	5	11
		<u>laurocerasus</u>	9	0	17	1	26	2
Tricholomataceae	<u>Laccaria</u>	<u>paludosa</u>	4	17	6	22	3	22
		<u>variata</u>	139	56	101	27	96	20
		<u>taccata</u>	12	26	28	35	45	40
		<u>flavovirens</u>	0	0	0	0	0	7
	<u>Tricholoma</u>	<u>resplendens</u>	0	1	2	1	14	11

(a) Because of the clumped distribution and small size of individual sporocarps, clumps rather than individuals were tallied.

(b) In 1984, individual sporocarps of L. rufus were tallied at first.

(c) Presence detected via fruiting of Cordyceps spp.



Table 6.4. Longevity in the field of flagged sporocarps of presumed ectomycorrhizal macrofungi.

Family	Genus	Species	Year	Number of Sporocarps Flagged	Longevity (weeks)			
					1	2	3	4
Amanitaceae	<u>Amanita</u>	<u>bisporigera</u>	1985	4	3			
			1984	8	5			
		<u>brunnescens</u>	1985	9	2		1	
			1984	3	0			
		<u>citrina</u>	1985	5	1			4
			1984	15	2			
		<u>muscaria</u>	1985	31	1	4	1	
			1984	13	4	1		
	<u>Amanitopsis</u>	<u>fulva</u>	1985	1	1			
			1984	2	0			
Boletaceae	<u>Boletellus</u>	<u>russellii</u>	1985	1	1			
			1984	0	-			
	<u>Boletus</u>	<u>piperatus</u>	1985	4	3			
			1984	1	0			
	<u>Leccinum</u>	<u>scabrum</u>	1985	9	1			1
Cantharellaceae	<u>Cantharellus</u>		1984	7	5			
		<u>lutescens</u>	1985	5				5
Cortinariaceae	<u>Cortinarius</u>		1984	1		1		
		<u>albopilulaceus</u>	1985	16	8			6
			1984	37	21	12		
		<u>armillatus</u>	1985	27	3	6	3	14
			1984	26	7	13	3	
		<u>flavifolius</u>	1985	4	2	1		
			1984	13	3	9		
		<u>semisanguineus</u>	1985	6				6
			1984	6	1	1		
		<u>sphaerosporus</u>	1985	14	5		2	1
			1984	0	-			
	<u>Rozites</u>	<u>trivialis</u>	1985	20	10			1
			1984	21	14			
		<u>caperata</u>	1985	20				1
			1984	34	15	3		
		<u>repandum</u>	1985	3	1			1
Hydnaceae	<u>Dentinum</u>		1984	7	1	3	1	2
Russulaceae	<u>Lactarius</u>	<u>argillaceifolius</u>	1985	14	3	8		
			1984	9	2	3	2	
		<u>rufus</u>	1985	0	-			
			1984	14	7			
		<u>subvolvireus</u>	1985	1				1
			1984	15	6	6	2	
		<u>terminosus</u>	1985	16	3		2	6
			1984	12	8	1		
	<u>Russula</u>	<u>brevipes</u>	1985	4				1
			1984	2	2			
		<u>emetica</u>	1985	21	3			2
			1984	15	4			
		<u>fragilis</u>	1985	4	0			
			1984	0	-			
		<u>laurocerasi</u>	1985	1		1		
			1984	0	-			
		<u>paludosa</u>	1985	3	0			
			1984	1	0			
Tricholomataceae	<u>Laccaria</u>	<u>laccata</u>	1985	3	1			2
			1984	14	5	9		
	<u>Tricholoma</u>	<u>flavovirens</u>	1985	10	3		4	
			1984	3	1			
		<u>resplendens</u>	1985	0	-			
			1984	5	3			

a. Number of specimens surviving in identifiable conditions; specimens are only reported once under the maximum age attained in identifiable condition.

## ELEMENT 7. MYCORRHIZA CHARACTERIZATION AND ROOT GROWTH

### Mycorrhizal Numbers and Morphology

Mycorrhizae embody finely balanced physiological relationships between the roots of higher plants and a number of highly specialized fungi beneficial to plant growth. Mycorrhizal fungi are obligately parasitic, requiring host photosynthate for energy. The matrix of mycorrhizal mycelium permeating the forest floor from infected roots provides the host with scarce minerals and water much more efficiently than could the host's roots alone.

Mycorrhizae are sensitive indicators of subtle environmental perturbations. As obligate symbionts, mycorrhizal fungi are intricately involved with more of the ecosystem than are many other components. They are sensitive not only to factors directly affecting their own physiological mechanisms, but also to factors which affect other living elements of the ecosystem, especially their hosts.

Mycorrhizae have been selected for use in other studies which required a sensitive indicator responsive to subtle changes that might not affect all organisms. Recent studies designed to monitor the effects of acid rain and ozone on natural ecosystems have used the percentage of host fine roots infected by mycorrhizal fungi as a criterion for evaluating host condition and the state of the symbiotic relationship as impacted by air pollution (Reich et al. 1985). Mycorrhizal studies are especially valuable for comparison with other measures of plant response, such as growth and plant moisture stress. It is possible that electromagnetic ELF effects too weak to directly invoke a measurable tree response could detectably alter the symbiotically fine-tuned mycorrhizal fungus component of the ecosystem.

Another characteristic of fungi in general which may render mycorrhizae relatively sensitive to electromagnetic ELF effects is the dependence of

fungal mycelium on intercellular electrical currents for growth. This electrical aspect of fungal physiology is just now being elucidated (Gow 1984; Harold et al. 1985). The physiological mechanisms which drive transcellular currents in fungi are still not clear, nor are the purposes for electrical current generation. Very low electrical currents have been found in all major groups of fungi (Gow 1984) and have been postulated to function in polarization of growth and in chemotrophic orientation (Harold et al. 1985). Most recently, it has been shown that transcellular currents in fungi are responsible for amino acid uptake, essential to the life of the organism (Kropf et al. 1985). For whatever reasons, the apparent dependence of fungi in general on very low electrical current generation for healthy growth may condition their susceptibility to other sources of electrical energy introduced into the ecosystem, such as those generated within an ELF field.

Populations of mycorrhizae developing at each plantation site are being compared with each other at monthly intervals and with corresponding values from previous years. The basic population units are individual seedlings. Individual mycorrhizae are categorized into morphological types which are produced by different fungal associations with red pine. Changes in both the partial frequencies of occurrence for different mycorrhizal types and the total numbers of mycorrhizal root tips per seedling will be quantified over time within and between sites. Data for analysis will be expressed as the mean number of mycorrhizae per gram (oven dry weight, 60°C) of seedling root mass. The working hypothesis is that there is no difference between plantation sites in the mean number of mycorrhizae per gram of seedling root mass. Changes reflected by alternative hypotheses include shifts in population species composition, increases or decreases of mycorrhizae and changes in character of morphology types.

### Sampling and Data Collection

In conjunction with plant moisture stress and tree growth studies (Element 3 - Tree Productivity), fifteen seedlings per site (five per plot) were sampled monthly during 1985. Though this is a one-third reduction in seedlings sampled compared to 1984, the number of mycorrhizae per seedling has increased on the average from five to ten times. As with last year, all seedlings analyzed for mycorrhizae development were also measured for top and root growth parameters, and moisture stress.

An important simplification in the characterization of mycorrhizae this past year was the combination of Type 2 and Type 3 mycorrhizae into a single type designated Type 3. Cultural information presented in the 1984 Report indicated that the fungi isolated from these two types are consistently the same. Apparently, Type 2 mycorrhizae are a younger stage of Type 3, as indicated by the continual gradation in appearance from one to another. Combining Type 2 into Type 3 eliminates the subjective decision where to draw the line between them and results in a much more natural classification system.

An additional modification involves the counting operation. Because of the large number of mycorrhizae occurring per seedling in the second year of outplanting (up to 30,000), it became necessary to subsample the seedling roots. This involved counting the mycorrhizae on a portion of each seedling root system separating, drying, and weighing this portion of the mycorrhizae and root mass, and then extrapolating the number of mycorrhizae for the entire root system based on the total root dry weight. The method was compared to actual total seedling counts in June, 1985, and found to be accurate. Differences between samples and total root counts, usually less than seven per cent, were not significant ( $\alpha=.05$ ). Non-mycorrhizal roots and mycorrhizae are expressed as number per gram (oven dry weight) of seedling root mass.

## Descriptions of Red Pine Mycorrhizal Types Recovered From ELF Plantations

### Type 3

Macroscopic -- Light buff to dark red brown, sometimes nearly black, usually lighter at apex; 2-10 mm long X 0.25-1.0 mm diameter; mono- or bipodal, occasionally multiply bifurcated and in mass forming coralloid clusters; plump and straight when short, but spindly and often crooked when long, usually somewhat constricted at the base.

Microscopic -- Surface hyphae sparse, 2-3 um diameter, bearing clamps; setae scattered, often clustered in bunches of 4-8, mostly 50-80 um long; mantle 10-20 um thick, thinner over apex, hyphae with conspicuous interlocking, "jig-saw puzzle-like" pattern; cortical cells red-brown except over apex where they are colorless; Hartig net hyphae bulbous and also with interlocking pattern.

Comments -- This is the common and most numerous type of mycorrhiza found originally on the nursery red pine seedlings. The causal fungi are most often Laccaria laccata and Telephora terrestris, though other fungi may also produce similar mycorrhizae.

### Type 5

Macroscopic -- Black, sometimes with lighter apex; usually fuzzy, with abundant attached, coarse hyphae; 1-3 mm long X 0.5-1.0 mm diameter; mono- or bipodal, seldom multiply bifurcated; often appearing as if dark hyphae are enveloping type 3 mycorrhizae.

Microscopic -- Surface hyphae dark-brown to black, 3-6 um diameter, septate; setae arising from central stellate points of interlocking surface hyphae, setae 100 um or greater in length mantle; 10-30 um thick, mantle surface of coiled and interlocking hyphae; cortical cells dark and covered directly

with Type 3 hyphae; Hartig net hyphae bulbous and also with interlocking pattern.

Comments -- This is a later stage mycorrhiza appearing to develop a sheath over an initially developed mycorrhiza. The causal fungus is Cenococcum graniforme.

#### **Type 6**

Macroscopic -- White to gray-brown, mottled and silvery; 2-5 mm long X 0.5-1.0 mm diameter; abundant loosely-bound surface hyphae often binding soil matter; mono- or bipodal often in large coralloid clusters of multiply bifurcated tips; in water, air bubbles become entrapped in loose surface hyphae causing free individuals to float.

Microscopic -- Surface hyphae colorless, abundant, septate, 3-6  $\mu$ m diameter, multiply branched at septae; setae lacking; mantle of loose hyphae 25-100  $\mu$ m thick; cortical cells red-brown covered with interlocking hyphae similar to Type 3; Hartig net hyphae bulbous and also with interlocking pattern.

Comments -- This is a later stage mycorrhiza appearing to develop a sheath over an initially developed mycorrhiza. Based on cultural characteristics, the causal fungus is probably a member of the Boletaceae.

#### **Progress**

Non-mycorrhizal roots on the planted red pine seedlings were present early in the season, steadily decreased through August, and were not found in September and October (Table 7.1). This pattern is understandable, considering the rapid elongation of root tips in the spring and the time required for natural inoculum to encounter and colonize roots. Once initial growth slows and fungal colonization occurs, non-mycorrhizal roots are seldom encountered. The only significant site difference in mean number of non-mycorrhizal roots occurred between the antenna and control sites in June; all other site comparisons were nonsignificant.

Table 7.1. Mean number and standard deviation of active non-mycorrhizal root tips per gram of root (o.d.w.) for red pine seedlings in 1985.

Month	Ground		Antenna		Control	
	Mean	S.D.	Mean	S.D.	Mean	S.D.
May	10 <sup>A</sup> 1/	6	12 <sup>A</sup>	10	11 <sup>A</sup>	5
June	5 <sup>EF</sup>	4	3 <sup>E</sup>	3	8 <sup>F</sup>	9
July	4 <sup>K</sup>	4	5 <sup>K</sup>	5	7 <sup>K</sup>	5
August	1 <sup>N</sup>	1	0 <sup>N</sup>	1	1 <sup>N</sup>	1
September	0 <sup>T</sup>	0	0 <sup>T</sup>	0	0 <sup>T</sup>	0
October	0 <sup>X</sup>	0	0 <sup>X</sup>	0	0 <sup>X</sup>	0

1/Values in rows denoted by different letters are significantly different at the  $\alpha = 0.05$  level.

Table 7.3. Mean number and standard deviation of total active mycorrhizal root tips per gram (o.d.w.) for red pine seedlings in 1985.

Month	Ground		Antenna		Control	
	Mean	S.D.	Mean	S.D.	Mean	S.D.
May	1055 <sup>A</sup> 1/	676	1315 <sup>A</sup>	756	1033 <sup>A</sup>	650
June	1294 <sup>E</sup>	697	888 <sup>E</sup>	409	852 <sup>E</sup>	742
July	746 <sup>K</sup>	446	1236 <sup>K</sup>	1055	1134 <sup>K</sup>	513
August	1101 <sup>N</sup>	625	967 <sup>N</sup>	842	642 <sup>N</sup>	460
September	1289 <sup>T</sup>	647	942 <sup>T</sup>	538	997 <sup>T</sup>	433
October	697 <sup>X</sup>	596	839 <sup>X</sup>	577	1282 <sup>X</sup>	763

1/Values in rows denoted by different letters are significantly different at the  $\alpha = 0.05$  level.

Table 7.2. Mean number and standard deviation of active Type 3 mycorrhizal root tips per gram of root (o.d.w.) for red pine seedlings in 1985.

Month	Ground		Antenna		Control	
	Mean	S.D.	Mean	S.D.	Mean	S.D.
May	1052 <sup>A</sup>	680	1250 <sup>A</sup>	776	1030 <sup>A</sup>	652
June	1284 <sup>E</sup>	700	880 <sup>E</sup>	405	846 <sup>E</sup>	742
July	729 <sup>K</sup>	454	1221 <sup>K</sup>	1049	1130 <sup>K</sup>	513
August	1089 <sup>N</sup>	622	961 <sup>N</sup>	841	631 <sup>N</sup>	456
September	1276 <sup>T</sup>	647	934 <sup>T</sup>	536	985 <sup>T</sup>	433
October	688 <sup>X</sup>	593	828 <sup>X</sup>	570	1263 <sup>X</sup>	760

1/Values in rows denoted by different letters are significantly different at the  $\alpha = 0.05$  level.

Table 7.4. Mean number and standard deviation of active Type 5 mycorrhizal root tips per gram of root (o.d.w.) for red pine seedlings in 1985.

Month	Ground		Antenna		Control	
	Mean	S.D.	Mean	S.D.	Mean	S.D.
May	3 <sup>A</sup>	12	62 <sup>A</sup>	132	2 <sup>A</sup>	9
June	10 <sup>E</sup>	21	9 <sup>E</sup>	13	6 <sup>E</sup>	6
July	10 <sup>K</sup>	10	15 <sup>K</sup>	18	4 <sup>K</sup>	6
August	11 <sup>N</sup>	22	6 <sup>N</sup>	9	10 <sup>N</sup>	16
September	12 <sup>T</sup>	18	8 <sup>T</sup>	11	8 <sup>T</sup>	10
October	9 <sup>X</sup>	12	11 <sup>X</sup>	12	26 <sup>X</sup>	30

1/Values in rows denoted by different letters are significantly different at the  $\alpha = 0.05$  level.

Type 3 mycorrhizae are by far the most common type encountered, representing well over ninety percent of the mycorrhizae occurring on the red pine seedlings (Tables 7.2 and 7.3). The decrease in Type 3 mycorrhiza abundance during the summer of 1984 and subsequent increase in the fall did not occur in 1985. This is likely due to improved seedling condition and growth in the second year supportive of large numbers of mycorrhizae throughout the growing season. When taken overall, there were no significant site differences in mean Type 3 mycorrhizae per gram of root among the sites.

Type 5 is the second most abundant mycorrhiza type but occurs at levels far below those of Type 3 (Table 7.4). This type occurred at all sites for all months sampled. As with Type 3, there were no significant monthly differences in Type 5 mycorrhizae per gram of root among sites.

Type 6 mycorrhizae are so sporadic in occurrence, having been encountered only two months at two sites (Ground in July and August, and Control in August), that they have not been included in the statistical analysis except as a part of the total mycorrhizae count. Type 6 mycorrhizae represents a unique, easily distinguishable type, the abundance of which will continue to be monitored for change in the years to come.

As Type 3 mycorrhizae account for the vast majority of mycorrhizae counted on the red pine seedlings, it follows that what has been shown in the analysis of this type is applicable to the total mycorrhizae per gram of root (Table 7.2). Again, no significant difference in mean monthly total mycorrhizae per gram of root occurred among sites.

Correlation matrices were calculated using all of the red pine seedling growth parameters measured at the ELF plantation study sites. Number of mycorrhizae and number of mycorrhizae per gram of root relate well to these other growth parameters. Total mycorrhizae correlates positively



( $\alpha = .001$ ) with seedling stem diameter ( $r^2 = .40$ ), seedling height ( $r^2 = .53$ ), seedling candle elongation ( $r^2 = .52$ ), seedling top weight ( $r^2 = .46$ ), and seedling root weight ( $r^2 = .50$ ), in addition to correlating positively ( $\alpha = .01$ ) with seedling bud set ( $r^2 = .22$ ). Number of mycorrhizae per gram of root correlated positively ( $\alpha = .001$ ) with seedling candle elongation ( $r^2 = .27$ ) and negatively ( $\alpha = .01$ ) with plant moisture stress (PMS) of seedlings ( $r^2 = -.21$ ).

Many of these growth variables are related to numbers of mycorrhizae. Those seedlings with fewer mycorrhizae per gram of root are also under the greatest moisture stress. This explains the negative correlation between mycorrhiza counts and PMS. Those seedlings with high numbers of mycorrhizae also have other favorable characteristics positively reflected as height, diameter, top weight, root weight, candle elongation and bud set. All of these parameters are indications of seedling vigor or quality. Since mycorrhizae are essential to a tree's health, all of the characters positively correlated with numbers of mycorrhizae are partially dependent on the tree's mycorrhizae development. These correlations further show that mycorrhizae are intricately tied to the growth physiology of the host. The presence of numerous significant correlations between mycorrhizae abundance and seedling growth variables at the ELF red pine plantation study sites is evidence that the mycorrhizal status of seedlings is a valid indication of overall seedling quality.

Since the red pine root systems are becoming much larger, alternate methods of sampling are being considered for 1986. Individual lateral roots may be excavated to serve as representative samples of root and mycorrhiza condition, or soil cores could be taken at specific depths and distances from random seedlings. Lateral roots bearing mycorrhizae removed from the cores would then be used for the mycorrhizae characterization and counting.

Soil cores have successfully been used in mycorrhizae studies, especially when mature trees or trees beyond the seedling stage are being studied (Harvey et al. 1981).

#### POSSIBLE ACID PRECIPITATION EFFECTS ON MYCORRHIZAE

The ELF project anticipates detecting any effects of low frequency electromagnetic fields on red pine seedlings and their associated mycorrhizae by comparing information gathered in the present base line period with that collected after the seedlings are exposed to the low frequency fields. Changes in levels of a variety of atmospheric contaminants could also effect morphological and physiological changes in seedlings and their associated microorganisms (Smith, 1981; Morrison, 1984).

There are indications that the incidence of acid precipitation may be increasing in the Upper Peninsula of Michigan. Most recent studies suggest that poorly buffered soils, such as those present on the ELF antenna site, are susceptible to perturbation by acid precipitation. In particular, soil organisms, including mycorrhizal fungi, might be affected by soil acidification. Several studies have examined the effects of acid rain on ectomycorrhizae of various trees (Stroo and Alexander, 1985; Shafer et al., 1985), but not red pine. Since mycorrhizae are an important component of the ELF Ecological Monitoring Program, a complementary parallel study was initiated to investigate possible effects of acid rain on mycorrhiza development in ELF antenna soils.

#### Sampling and Data Collection

Soil was collected at the ELF antenna site to fill 210 three-gallon pots. Red pine seedlings (2-0) were obtained from the Toumey Nursery and planted in the plots in early July. The pots were evenly divided into three groups, each of which is being treated with a different pH concentration of simulated rain water. This simulation was based on a standard rain water

solution developed by the National Bureau of Standards and has a pH of 5.5. Two subsamples of this rain water were acidified to a pH of 3.0 and 4.0 using a 2.2:1  $\text{HNO}_3$  solution. A third subsample acted as a control (pH 5.5). Each week the pots are watered with 700 to 900 mls of the assigned rainwater solution. The pots were protected from ambient rainfall under a wooden frame covered with 4 ml plastic sheeting. On September 30, pots were moved into the greenhouse at Michigan Technological University and the treatments continued.

Every six weeks 42 randomly selected pots (14 from each treatment group) are harvested and studied. Seedling roots are examined to determine the numbers and types of mycorrhizae present, and the numbers of non-mycorrhizal root tips. The seedling root/shoot ratio is also determined. Foliage and root weights are obtained and subsamples are taken for nutrient analyses.

Potential buffering effects resulting from microbial activity in the rhizosphere may moderate acidic conditions near the root, and modify the possible mycorrhizal inhibition. To investigate this effect, the soil in the pots is sampled at various distances from the roots for determination of pH, cation concentration, and levels of  $\text{NO}_3$  and  $\text{SO}_4$ .

Six samplings of the pots will be done with the final harvest on March 15, 1986. This will allow for observations focusing on the gradual changes in mycorrhizae and seedling physiology over time. Chemical and mycorrhizal analysis has been ongoing and will be completed by June, 1986.

## ELEMENT 8. LITTER PRODUCTION

Litter fall and decomposition is important in the transfer of nutrients and energy within a vegetative community. The sensitivity of foliage production to both tree physiological changes and nonindependent external climatic conditions make it a good indicator of possible ELF field effects on trees. Since litter samples can be gathered at frequent intervals, they not only provide an estimate of changes in canopy production, but also give an insight on tree phenological events such as leaf fall, bud burst, seed, dissemination, and time of flowering. Additionally, leaf samples taken during the growing season for nutrient analysis and weight determination would monitor nutrient accumulation and subsequent translocation from the foliage to the branches prior to leaf fall. This physiological process is also sensitive to environmental stress and would be a potential indicator of ELF field effects.

The objective of this element is to obtain information on total litter weight and nutrient content, and foliar nutrient levels of northern red oak during the growing season on the antenna and control plots prior to the operation of the ELF communication system. Two overall null hypotheses will be tested in this study:

$H_0$ : There is no difference in the total weight of litter fall (leaves, wood, and miscellaneous) before and after the ELF antenna becomes operational.

$H_0$ : There is no difference in the foliar nutrient concentrations of northern red oak trees before and after the ELF antenna becomes operational

Each year prior to an operational antenna, a baseline relationship of the ecological systems is established through tests of the following hypotheses:

$H_0$ : There is no difference in the total weight of litter fall between the antenna and control site within a year.

$H_0$ : There is no difference in the foliar nutrient concentrations of northern red oak trees between the antenna and control site within a year.

The resulting ANOVA table for the analysis of each litter component each year is shown below.

<u>Source of Variation</u>	<u>df</u>	<u>SS</u>	<u>MS</u>	<u>F</u>
Plot	2	$SS_P$	$MS_P$	$MS_P/MS_{E(S)}$
Site	1	$SS_S$	$MS_S$	$MS_S/MS_{E(S)}$
Error(s)	26	$SS_{E(S)}$	$MS_{E(S)}$	
Year	#yrs-1	$SS_Y$	$MS_Y$	$MS_Y/MS_{E(Y)}$
Site x year	(1)(#yrs-1)	$SS_{SXY}$	$MS_{SXY}$	$MS_{SXY}/MS_{E(Y)}$
Error (y)	$24+4(\text{\#yrs}-1)$	$SS_{E(Y)}$	$MS_{E(Y)}$	

#### Sampling and Data Collection

Five 1x1 meter litter traps are being used to monitor tree litter production on each permanent measuring plot at the antenna and the control sites. Litter was collected at intervals during the summer and weekly after the onset of leaf fall in early September. Crown nutrient concentrations and translocation in northern red oak leaves are being examined by collecting foliage samples at both the antenna and control site during the summer months. An analysis of stem diameter data indicated that sampling trees of 15 cm, 21 cm and 32 cm would adequately represent the distribution of red oak on each site. Three trees of each diameter were located off of the permanent measurement plots at each site to minimize disturbance. Leaf samples were obtained from near the top of the crown using a 12 gauge shotgun with a full choke.

All litter and foliage samples were dried at 60 C in a forced draft oven. The litter was separated into the following categories: (1) leaves, (2) wood, (3) miscellaneous and weighed. A representative subsample of ten leaves was taken from each foliage collection and weighed. All samples were ground to pass a 40 mesh sieve and were analyzed for N by Kjeldahl digestion, P by the vanadomolybdate method, and Ca, Mg and K by atomic absorption spectrophotometry.

### Progress

The major litter fall in the ELF study area occurred later in 1985 than was found in 1984, but was similar to 1983 (Figure 8.1). The major leaf fall started by September 25 and was completed by October 24 on both the antenna and control sites (Figure 8.2). No significant differences in leaf, wood and miscellaneous tree litter were evident between the two sites in 1985. Comparing litter fall amount in 1985 to that of 1984, only the woody tree components were different at both sites (Table 8.2). This yearly variability among woody material is not unexpected, since wood litter fall is strongly influenced by individual storm events rather than by average seasonal growing conditions.

**Table 8.2. Total litter fall at the antenna and control sites**

	<u>Leaves</u>	<u>Wood</u>	<u>Misc.</u>
	- - - - - (gm/Sq m) - - - - -		
<u>Antenna</u>			
1984	307.2 <sup>A</sup>	44.0 <sup>L</sup>	33.8 <sup>X</sup>
1985	322.4 <sup>A</sup>	25.0 <sup>M</sup>	30.5 <sup>X</sup>
<u>Control</u>			
1984	357.0 <sup>A</sup>	53.8 <sup>L</sup>	27.5 <sup>X</sup>
1985	333.1 <sup>A</sup>	34.7 <sup>M</sup>	24.8 <sup>X</sup>

Collection Period: 1984 - June 20 to October 24;  
1985 - June 20 to October 23.

Values in columns denoted by different letters are significantly different at the  $\alpha=0.05$  level.

FIGURE 8.1  
CUMULATIVE LEAF FALL  
1984 VS 1985

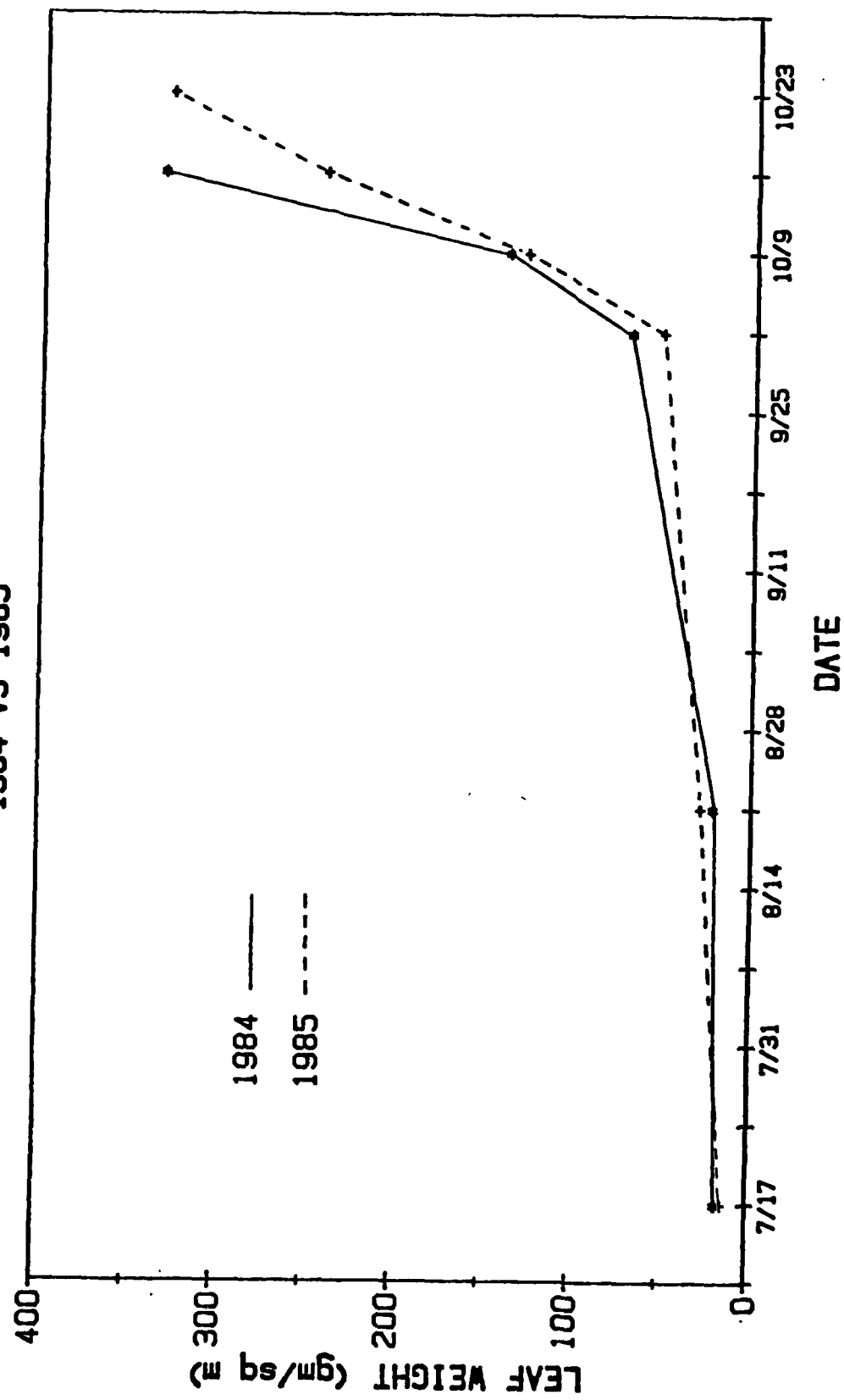
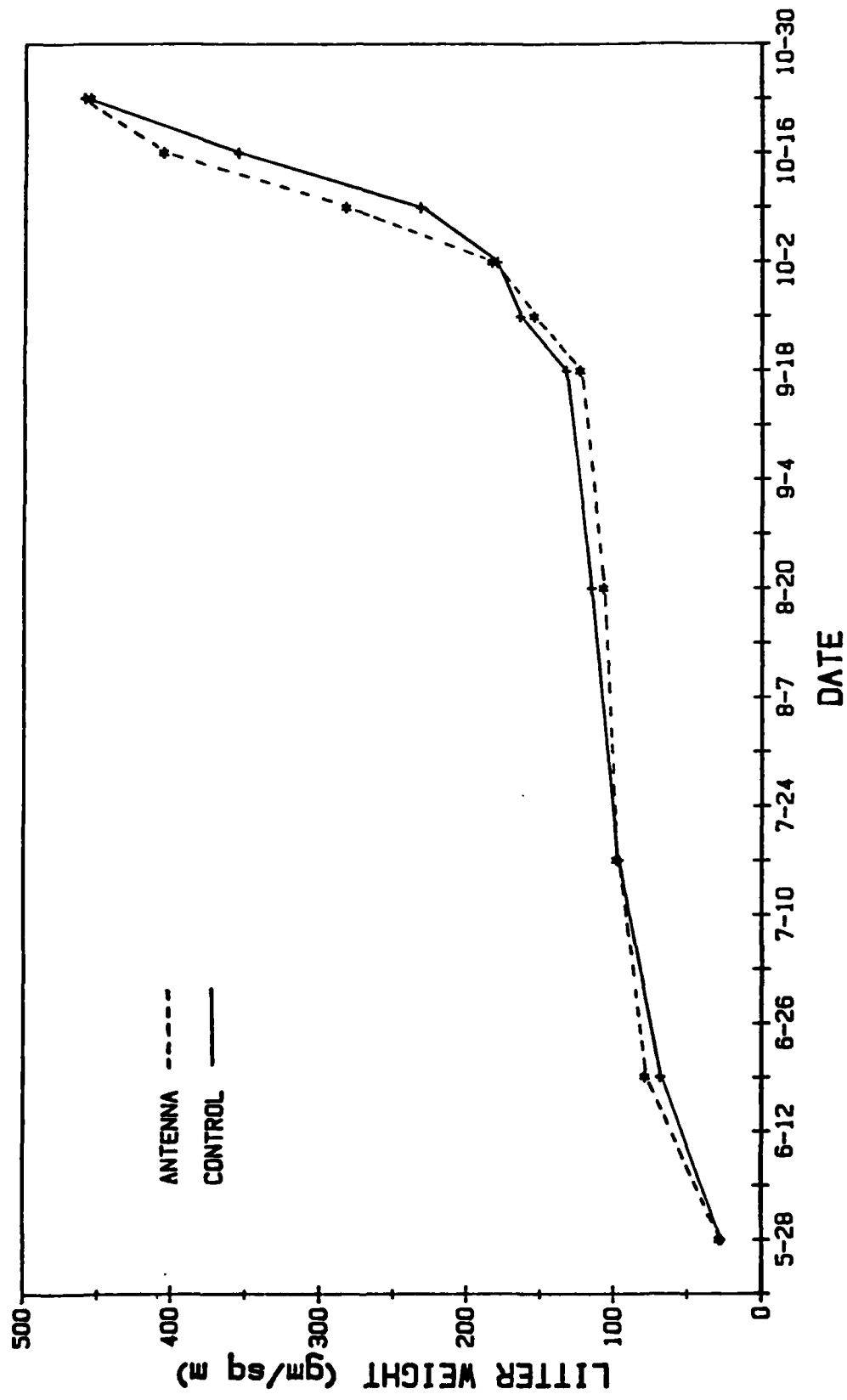


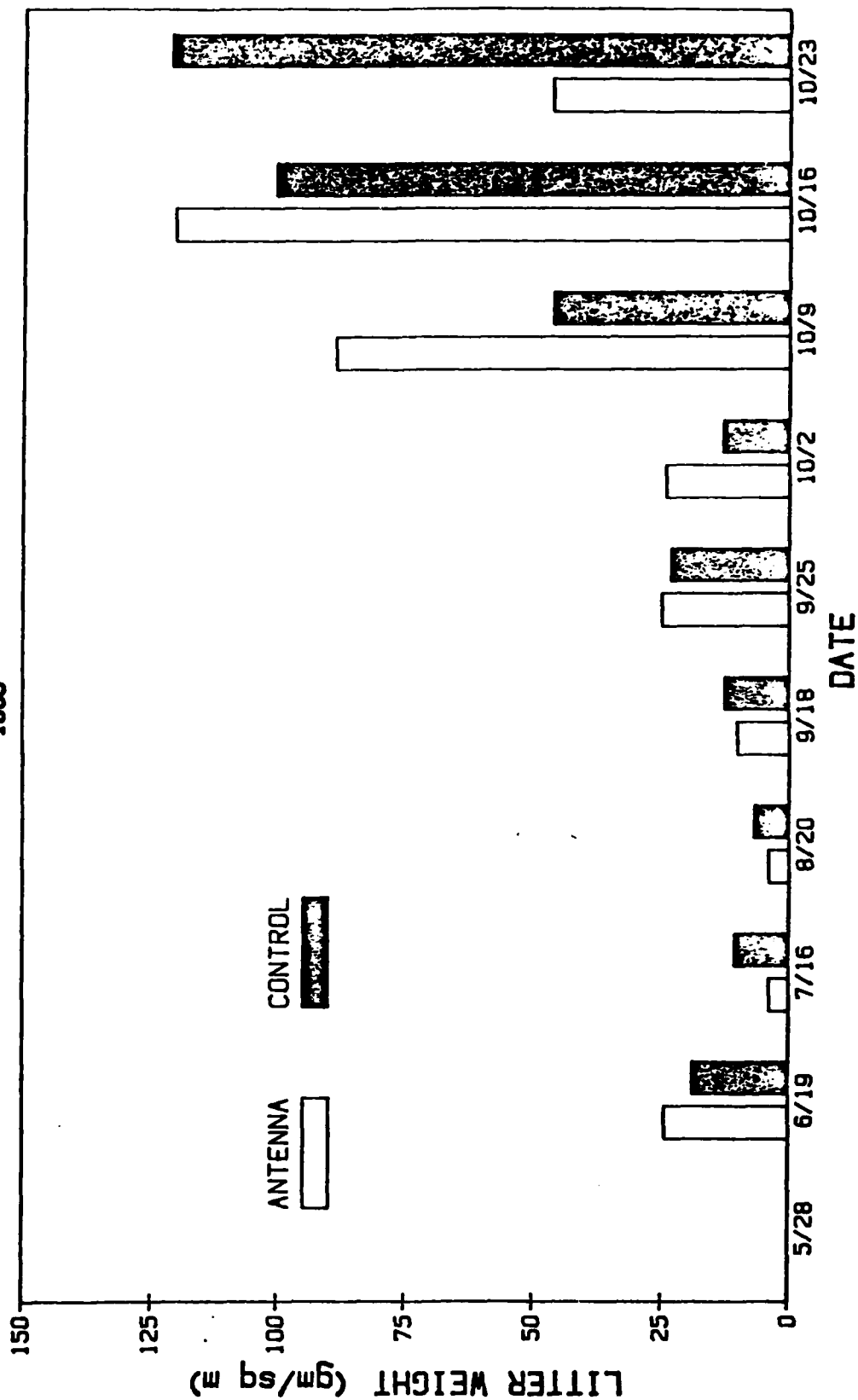
FIGURE 8.2  
CUMULATIVE LITTER FALL  
1985





# LEAF LITTER FALL 1985

FIGURE 8.3



Periodic litter fall amounts varied considerably between the antenna site and the control site at all collection times in the fall (Figure 8.3). These differences in weekly leaf fall were related to the variable tree species composition at each site. The leaf litter at the antenna site has a much higher proportion of red maple and big tooth aspen than the control. In contrast, northern red oak litter predominates on the control site (Table 8.3). Oak leaves remain on the trees longer than the maple or aspen and account for much of the litter fall variations between locations.

**Table 8.3. Leaf litter fall by tree species at the antenna and control sites - 1985**

<u>Tree</u>	<u>Antenna</u>		<u>Control</u>	
	<u>Weight</u>	<u>%</u>	<u>Weight</u>	<u>%</u>
	- - -(gm/m <sup>2</sup> )- - -		- - -(gm/m <sup>2</sup> )- - -	
Red Maple	135	45	42	14
Red Oak	93	31	227	75
Bigtoothed Aspen	45	15	14	5
Paper Birch	25	9	19	6
Red Pine	1	1	0	0

Chemical analysis of the 1984 litter samples were completed this past year (Table 8.4). Only small differences in total nutrient amounts added to the forest floor on each site by litter fall were found. This reflects the similar total litter weight on both the antenna and control site in 1984. Nutrient analysis of the 1985 litter samples are currently underway.

Table 8.4. Nutrient content of litter fall during 1984 at the antenna and control sites\*

	<u>Antenna</u>	<u>Control</u>
<u>Leaves</u>	(Kg/ha)	
N	24.2	34.0
P	3.4	4.0
Ca	35.0	42.6
Mg	5.8	6.9
K	9.0	12.5
<hr/>		
<u>Wood</u>		
N	2.5	3.0
P	0.3	0.3
Ca	5.3	8.2
Mg	0.3	0.4
K	0.8	1.0
<hr/>		
<u>Miscellaneous</u>		
N	6.3	3.2
P	0.5	0.3
Ca	2.0	1.3
Mg	0.3	0.2
K	1.6	1.7

\*Collection period: 6/20 - 10/24

Foliage sampling of northern red oak in 1985 did not show significant leaf weight differences (average weight 0.62 gm, s.d. 0.14 gm) between the two sites at any of the three sampling dates or among the three tree sizes sampled. Chemical analyses of the 1984 red oak foliage samples were completed and showed no differences in the concentration of five macronutrients between the antenna and control sites. However, sampling date had a significant effect on the leaf concentration of all nutrients which reflected the translocation of nutrients out of the foliage prior to leaf abscission (Table 8.5). Tree diameter had a significant effect on the foliar concentration of potassium and magnesium, but not nitrogen, phosphorus or calcium. Nutrient analysis of the 1985 red oak foliage samples are currently being conducted.

**Table 8.5. Nutrient concentration of northern red oak foliage as affected by tree size and sampling date**

<u>Nutrient</u>	<u>Tree Diameter</u>		
	<u>15 cm</u>	<u>21 cm</u>	<u>32 cm</u>
	- - - - - (%) - - - - -		
N	1.95 <sup>A</sup>	1.82 <sup>A</sup>	1.92 <sup>A</sup>
P	0.17 <sup>D</sup>	0.19 <sup>D</sup>	0.19 <sup>D</sup>
K	0.79 <sup>G</sup>	0.66 <sup>H</sup>	0.70 <sup>H</sup>
Ca	0.81 <sup>L</sup>	0.82 <sup>L</sup>	0.81 <sup>L</sup>
Mg	0.16 <sup>X</sup>	0.17 <sup>X</sup>	0.13 <sup>Y</sup>

---

	<u>Sampling Date</u>		
	<u>August</u>	<u>September</u>	<u>October</u>
	- - - - - (%) - - - - -		
N	2.20 <sup>A</sup>	2.05 <sup>A</sup>	1.45 <sup>B</sup>
P	0.16 <sup>D</sup>	0.19 <sup>E</sup>	0.20 <sup>E</sup>
K	0.77 <sup>G</sup>	0.80 <sup>G</sup>	0.59 <sup>H</sup>
Ca	0.80 <sup>L</sup>	0.78 <sup>L</sup>	0.92 <sup>M</sup>
Ma	0.17 <sup>X</sup>	0.15 <sup>Y</sup>	0.14 <sup>Y</sup>

Values in rows denoted by different letters are significantly different at the  $\alpha=0.05$  level.

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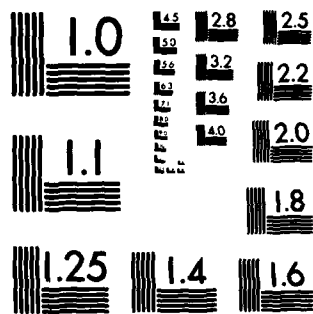
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MICROCOPY RESOLUTION TEST CHART  
NATIONAL BUREAU OF STANDARDS-1963-A

**APPENDIX A**

**Profile Descriptions of the Soil Occurring  
on the Ground, Antenna, and Antenna Sites**

## Antenna Site

Pedon Classification: Entic Haplorthod, sandy, mixed, frigid.

Soil No.: R83M1103-1

Location: Marquette County, Michigan

Vegetation and Land Use: Northern hardwoods. Forested.

Parent Material: Outwash over water-worked till.

Physiographic Position: Rolling upland.

Topography: Undulating. Gradient is 7 percent. South aspect. Concave. Slope length is 200 ft.

Drainage: Well drained.

Groundwater: Below 160 cm.

Sampled by: C. Trettin, C. Becker, E. Padley, K. Warren.

(All colors are for moist condition unless otherwise stated.)

0i 2 to 1 cm (1 to .2 inches). Undecomposed hardwood litter.

0a 1 to 0 cm (.2 to 0 inches). Well decomposed hardwood litter; many fine and common medium roots.

A 388 0 to 2 cm (0 to 1 inch). Black (N2/) loamy sand; weak fine granular structure; very friable; many fine and medium, and few coarse roots; very strongly acid; abrupt smooth boundary. (2 to 3 cm thick)

E 389 2 to 13 cm (1 to 5 inches). Pinkish gray (7.5YR 6/2) sand; weak fine granular structure; very friable; many fine and medium, and common coarse roots; 2 percent coarse fragments; strongly acid; abrupt wavy boundary. (5 to 13 cm thick)

Bs1 390 13 to 27 cm (5 to 11 inches). Dark brown (7.5YR 4/4) loamy sand; weak fine subangular blocky structure; friable; many fine and medium, and common coarse roots; 3 percent coarse fragments; strongly acid; abrupt wavy boundary. (12 to 16 cm thick)

Bs2 391 27 to 43 cm (11 to 17 inches). Yellowish red (5YR 4/6) fine sand; weak fine subangular blocky structure; friable; common fine and medium, and few coarse roots; 3 percent coarse fragments; moderately acid; clear wavy boundary. (12 to 19 cm thick)

Bs3 392 43 to 66 cm (17 to 26 inches). Strong brown (7.5YR 5/6) sand; weak fine granular structure; very friable; few fine and medium roots; 1 percent coarse fragments; moderately acid; clear irregular boundary. (22 to 65 cm thick)

2Bc 393 66 to 90 cm (26 to 35 inches). Dark brown (7.5YR 4/4) very stony loamy sand; moderate medium subangular blocky structure; friable; few fine and medium roots; 30 percent coarse fragments in stone line at top of till; moderately acid; gradual wavy boundary. (23 to 28 cm thick)

2C 394 90 to 160 cm (35 to 63 inches). Strong brown (7.5YR 4/6) very stony loamy sand; weak fine granular structure; friable; few fine and medium roots; 30 percent coarse fragments; moderately acid.

## Ground Site

Pedon Classification: Typic Dystrochrept, sandy, mixed, frigid.

Soil No.: R83M1103-2

Location: Marquette County, Michigan

Vegetation and Land Use: Northern hardwoods. Forested.

Parent Material: Outwash.

Physiographic Position: Rolling. Upland.

Topography: Undulating.

Drainage: Well drained.

Groundwater: Below 175 cm.

Sampled by: C. Trettin, P. Cattellino.

(All colors are for moist condition unless otherwise stated.)

0a 3 to 0 cm (1 to 0 inches). Well decomposed hardwood litter.

A 407 0 to 5 cm (0 to 2 inches). Dark reddish brown (5YR 2.5/2) loamy sand; weak fine granular structure; friable; many fine and medium, and few coarse roots; 3 percent coarse fragments; abrupt wavy boundary. (2 to 6 cm thick)

E 408 5 to 14 cm (2 to 6 inches). Pinkish gray (5YR 6/2) sand; weak fine granular structure; very friable; many fine and medium, and common coarse roots; 3 percent coarse fragments; abrupt wavy boundary. (6 to 23 cm thick)

Bs1 409 14 to 45 cm (6 to 18 inches). Yellowish red (5YR 5/6) sand; weak fine subangular blocky structure; friable; common fine and medium roots; 2 percent coarse fragments; clear wavy boundary. (19 to 38 cm thick)

Bs2 410 45 to 72 cm (18 to 28 inches). Yellowish red (5YR 5/8) sand; weak fine subangular blocky structure; very friable; common fine and few medium roots; 15 percent coarse fragments with a stone line comprised of rounded cobbles; clear wavy boundary. (18 to 24 cm thick)

2Bt 411 72 to 92 cm (28 to 36 inches). Strong brown (7.5YR 4/6) fine sandy loam with few thin reddish brown (5YR 4/4) clay films; medium subangular blocky structure; friable; few fine and medium roots; 50 percent coarse fragments; clear wavy boundary. (9 to 21 cm thick)

2C 412 92 to 175 cm (36 to 69 inches). Dark reddish brown (5YR 3/4) sandy loam; weak fine granular structure; friable; few fine and medium roots; 70 percent coarse fragments.

## Control Site

188.

Pedon Classification: Alfic Haplorthod; coarse-loamy, fixed, frigid.

Series Classification: (Sere)

Soil:

Plot and Study: FLF (Control Site)

Location: Iron County, Michigan. SE, SE Section 3, T41N, R32W.

Climate: Average annual precipitation is about 250 mm; mean annual air temperature is about 8°C.

Vegetation and Land Use: Woodland (Red oak, white birch, aspen, sugar maple).

Parent Material: Glacial till.

Physiographic Position: Rolling upland.

Topography: Complex slopes. Gradient is 3 to 5 percent. Southeast aspect. Concave, upper slope position. Slope length is 30 meters.

Groundwater: Below 230 cm.

Sampled by: R. Wendell, B. Wilczynski. September 20, 1984.

(All colors are for moist conditions.)

O1 548 5 to 2 cm. Undecomposed hardwood leaves and twigs; very strongly acid; abrupt smooth boundary. (2 to 3 cm thick)

Oe 549 2 to 0 cm. Partially decomposed hardwood litter; very strongly acid; abrupt smooth boundary. (0 to 2 cm thick)

A 550 0 to 4 cm. Dark reddish brown (5YR 2.5/2) fine sandy loam; weak fine granular structure; very friable; many fine roots; extremely acid; clear smooth boundary. (2 to 5 cm thick)

E 551 4 to 9 cm. Pinkish gray (5YR 6/2) fine loamy sand; weak fine subangular blocky structure; friable; many fine and common medium roots; extremely acid; clear wavy boundary. (5 to 9 cm thick)

Pt1 552 9 to 32 cm. Yellowish red (5YR 4/6) fine loamy sand; moderate medium subangular blocky structure; friable; many fine, common medium and few coarse roots; 3 percent pebbles; medium acid; gradual smooth boundary. (15 to 23 cm thick)

Pt2 553 32 to 55 cm. Yellowish red (5YR 5/8) fine sand; strong medium subangular blocky structure; friable; few fine and many medium roots; 4 percent pebbles; slightly acid; clear smooth boundary. (20 to 23 cm thick)

E' 554 55 to 67 cm. Reddish brown (5YR 5/3) fine sandy loam; moderate medium subangular blocky structure; friable; few medium roots; few fine vesicular pores; 9 percent pebbles; medium acid; gradual smooth boundary. (12 to 14 cm thick)

(E/E)1 555 67 to 105 cm. Reddish brown (5YR 4/4) gravelly fine sandy loam (Pt) and light reddish brown (5YR 6/4) fine loamy sand (E); strong fine subangular blocky structure (Pt) and strong medium subangular blocky structure (E); friable; few fine and few medium roots; few fine vesicular pores; 34 percent pebbles; medium acid; gradual smooth boundary. (38 to 40 cm thick)

(E/E)2 556 105 to 124 cm. Red (2.5YR 4/6) sandy loam (Pt) and yellowish red (5YR 5/6) loamy sand (E); strong medium subangular blocky structure; friable; few fine roots; few very fine vesicular pores; 13 percent pebbles; slightly acid; clear smooth boundary. (17 to 19 cm thick)

C 557 124 to 230 cm. Yellowish red (5YR 5/6) sand; single grain; loose; 8 percent pebbles; slightly acid; few irregularly spaced red (2.5YR 4/6) loamy sand bands.

NOTE: A layer with 70 percent pebble content occurred between 89 and 109 cm.

**APPENDIX B**

**Ambient Sensor Configuration, Sampling Periods,  
and Ambient Summary Tables**

Table 1. Sensor Configuration

Ground			
Plot 1	Plot 2	Plot 3	
AT1 SP	AT1 GSR	AT1	
ST5	ST5 RH	ST5	
SM5	SM5 PR	ST10	
ST10	ST10	ST10	
SM10	SM10	SM10	
Antenna			
Plantation			
Plot 1	Plot 2	Plot 3	
AT1 SP	AT1	AT1	
ST5 RH	ST5	ST5	
SM5 PR	SM5	SM5	
SM10	SM10	SM10	
Pole-Size Tree			
Plot 1	Plot 2	Plot 3	
AT1 PSR	AT1	AT1	
ST5 AT2	ST5	ST5	
SM5	SM5	ST10	
SM10	SM10	SM10	
Control			
Plot 1	Plot 2	Plot 3	
AT1	AT1 PSR	AT1	
ST5	ST5 AT2	ST5	
SM5	SM5	ST10	
ST10	ST10	SM10	
SM10	SM10		

Legend

- AT1 - Air Temperature (2 meters above ground)
- ST5 - Soil Temperature (Depth 5 cm)
- SM5 - Soil Moisture (Depth 5 cm galvanic probe)
- ST10 - Soil Temperature (Depth 10 cm)
- SM10 - Soil Moisture (Depth 10 cm galvanic probe)
- GSR - Global Solar Radiation
- RH - Relative Humidity
- PR - Precipitation
- SP - Snow Pillow
- PSR - Photosynthetic Active Radiation (300-700nm)
- AT2 - Air Temperature 20m above ground



Table 2

Sensor Sampling Interval  
and Reported Measurement Form

Sensor	Sampling Interval	Logged Measurement
Soil Temperature	1/30 min.	3 hr. average
Air Temperature (1 Air Temperature in each plantation and pole-sized stand)	1/30 min.	3 hr. average
Relative Humidity	1/60 min.	1 hr. average
Soil Moisture	1/30 min.	3 hr. average
Photosynthetic Active Radiation	1/180 min.	3 hr. average
Global Radiation	1/30 min.	3 hr. average
		1 hr. average

Table 3

Average Weekly Air Temperature  
on the Ground and Control Plantations

Mid-Week Date	<u>Ground</u>		<u>Control</u>		<u>Control- Ground</u>	
	Ave. C°	St.D	Ave. C°	St.D°	Ave. C°	
4-15	3.2 <sup>+</sup>	.19	4.5	.33	1.3	*
4-22	14.6 <sup>+</sup>	.04	16.7		2.1	*
4-29	7.7 <sup>+</sup>	.00	9.8	0.0	2.1	*
5-6	9.7 <sup>+</sup>	.04	11.0	.59	1.4	*
5-12	15.6	.04	15.1	.12	-0.5	*
5-19	10.3	.06	10.5	.32	0.2	
5-26	11.3	.08	12.1	.26	0.8	*
6-2	10.8	.04	11.7	.29	0.9	*
6-9	13.0 <sup>+</sup>		13.1	.08	0.1	
6-16	12.2 <sup>+</sup>		12.9	.08	0.7	
6-23	14.6 <sup>+</sup>		15.5	.04	0.9	*
6-30	17.3	.00	18.4	.04	0.9	*
7-7	16.5	.12	16.8	.00	0.3	
7-14	16.4	.12	17.5	.04	1.1	*
7-21	16.7	.12	17.5	.00	0.8	*
7-28	16.9	.06	16.6	.04	-0.3	
8-4	17.7 <sup>+</sup>		18.5	.04	0.8	
8-11	17.0 <sup>+</sup>		17.4	.10	0.4	
8-18	13.8 <sup>+</sup>		14.0	.08	0.2	
8-25	15.1 <sup>+</sup>		15.2	.06	0.1	
9-1	14.6 <sup>+</sup>		15.0	.11	0.4	
9-8	14.5	.14	15.5	.23	1.1	*
9-15	11.3	.03	11.9	.17	0.6	*
9-22	11.6	.08	12.4	.78	0.8	*
9-29	6.1	.06	6.1	.23	0.0	
10-6	6.6	.06	6.8	.14	0.2	
10-13	5.4	.06	6.0	.14	0.6	*
10-20	6.5	.21	7.3	.20	0.8	*
10-27	6.8	.08	7.3	.17	0.5	*
Wk 1-29	12.2	4.21	12.8	4.15	0.6	*

\* Denotes significant difference at 5% between sites for a given week.

+ Denotes weeks taken from antenna site.

Table 4

Average Weekly Air Temperature on  
the Control and Antenna Plantations

Mid-Week Date	<u>Ground</u>		<u>Control</u>		<u>Control- Antenna</u>	
	Ave. °	St.D	Ave. °	St.D	Ave. °	
4-15	3.2 <sup>+</sup>		4.5	.33	1.3	*
4-22	14.6 <sup>+</sup>		16.7		2.1	*
4-29	7.7 <sup>+</sup>		9.8	0.0	2.1	*
5-6	9.7 <sup>+</sup>		11.0	.59	1.3	*
5-12	15.2	.12	15.1	.12	-0.1	
5-19	10.1	.04	10.5	.32	0.4	
5-26	11.2	.27	12.1	.26	0.9	*
6-2	10.6	.24	11.7	.29	1.1	*
6-9	13.0	.08	13.1	.08	0.1	
6-16	12.2	.40	12.8	.08	0.6	*
6-23	14.6	.51	15.5	.04	0.9	*
6-30	17.5	.82	18.4	.04	0.9	*
7-7	16.3	.20	16.8	.00	0.5	
7-14	15.9	1.10	17.5	.04	1.6	*
7-21	16.6	.51	17.5	.00	0.9	*
7-28	16.8	.35	16.6	.04	-0.2	
8-4	17.7	.20	18.5	.04	0.8	
8-11	16.9	.31	17.4	.10	0.5	
8-18	13.8	.04	14.0	.08	0.2	
8-25	15.1	.00	15.2	.06	0.1	
9-1	14.6	.00	14.9	.11	0.3	
9-8	15.2	.08	15.5	.23	0.3	
9-15	11.9	.04	11.9	.17	0.0	
9-22	11.6	.08	12.4	.77	0.8	
9-29	6.2	.04	6.1	.23	-0.1	*
10-6	6.7	.08	6.8	.14	0.1	
10-13	5.6	.00	6.0	.14	0.4	*
10-20	7.2	.04	7.3	.20	0.1	
10-27	7.0	.04	7.3	.17	0.3	
Wk 1-29	12.1	4.13	12.8	4.15	0.6	

\* Denotes significant difference at 5% probability.

<sup>+</sup> Denotes weekly average from ground site.

Table 5

Average Weekly Air Temperature  
on Control and Antenna Pole-Sized Tree Plots

Mid Week Date	<u>Ground</u>		<u>Control</u>		<u>Control- Antenna</u>	
	Ave. C°	St.D	Ave. C°	St.D	Ave. C°	
4-15	3.2 <sup>+</sup>		4.6	.15	1.4	*
4-22	14.6 <sup>+</sup>		17.6	.21	3.0	*
4-29	7.7 <sup>+</sup>		9.9	.85	2.2	*
5-6	9.7 <sup>+</sup>		11.9	.24	2.2	*
5-12	15.2	.06	15.5	.36	0.3	
5-19	10.1	.21	10.6	.24	0.5	*
5-26	11.2	.19	12.5	.16	0.7	*
6-2	10.5	.20	11.7	.06	1.2	*
6-9	12.9	.13	13.5	.03	0.6	*
6-16	12.4	.12	13.0	.06	0.6	*
6-23	14.1	.16	15.7	.03	1.6	*
6-30	17.6	.17	18.5	.06	0.9	*
7-7	16.2	.21	17.1	.03	0.9	*
7-14	16.4	.18	17.8	.10	1.4	*
7-21	16.8	.11	17.9	.08	1.1	*
7-28	16.4	.27	17.2	.11	0.8	*
8-4	17.6	.31	18.6	.04	1.0	*
8-11	16.9	.06	17.6	.08	0.7	*
8-18	13.7	.06	14.3	.06	0.6	*
8-25	14.8	.06	15.4	.06	0.6	*
9-1	14.3	.16	15.1	.06	0.8	*
9-8	14.9	.08	15.6	.03	0.7	*
9-15	11.6	.24	12.4	.03	0.8	*
9-22	11.6	.06	12.7	.88	1.1	*
9-29	6.1	.06	6.2	.06	0.1	
10-6	6.7	.08	7.3	.03	0.6	*
10-13	5.4	.15	6.3	.03	0.9	*
10-20	7.1	.29	7.9	.01	0.8	*
10-27	6.7	.25	7.8	.12	0.9	*
Wk 1-29	12.7	3.86	13.2	4.14	0.5	

\* Denotes significant difference between sites for a given week.

+ Denotes temperature from ground site.

Table 6

Average Weekly Soil Temperature at 5 cm  
on the Ground and Control Plantations

Mid-Week Date	<u>Ground</u>		<u>Control</u>		<u>Control- Ground</u>
	Ave. C°	St.D	Ave. C°	St.D	Ave. C°
4-15	0.6	.71	0.9	1.02	0.3
4-22	10.6	.39	10.1	1.71	-0.5
4-29	9.2	.24	8.4	.45	-0.8
5-6	10.6		10.6	.12	0.0
5-12	14.7	.28	14.6	.28	-0.1
5-19	12.9	.25	12.1	.04	-0.8
5-26	14.1	.37	13.5	.12	-0.6
6-2	14.2	.39	13.5	.28	-0.7
6-9	16.7	.39	15.0	.43	-1.7 *
6-16	15.1	.57	14.4	.36	-0.7
6-23			15.8	.55	
6-30	18.6	.06	18.9	.74	0.3
7-7	17.9	.20	18.0	.52	0.1
7-14	17.7	.23	18.2	.68	0.5
7-21	17.9	.38	18.4	.51	0.5
7-28	17.7	.42	17.9	.64	0.2
8-4			18.7	.79	
8-11			18.1	.26	
8-18			15.9	.23	
8-25			15.8	.22	
9-1			15.8	.22	
9-8	16.2	.11	16.6	.23	0.4
9-15	12.5	.42	12.7	.26	0.2
9-22	13.5	.25	14.5	.22	1.0
9-29	8.6	.33	8.6	.21	0.0
10-6	8.0	.20	8.1	.31	0.1
10-13	7.2	.31	7.0	.51	-0.4
10-20	6.9	.43	6.5	.41	-0.4
10-27	6.9	.32	6.5	.41	-0.4
Wk 1-10					
12-16					
22-29	12.5	4.69	12.4	4.78	0.1

\* Denotes significant difference at 5% level.

Table 7

Average Weekly Soil Temperature at 10 cm  
on the Ground and Control Plantations

Mid-Week Date	<u>Ground</u>		<u>Control</u>		<u>Control- Ground</u>
	Ave. C°	St.D	Ave. C°	St.D	Ave. C°
4-15	.3	.16	.2	.18	-0.1
4-22	9.4	.20	5.6	2.12	-3.8 *
4-29	8.9	.24	8.4	.93	-0.5
5-6	9.9	.24	10.4	.23	0.5
5-12	14.1	.33	14.2	.17	0.1
5-19	12.5	.41	12.3	.48	-0.2
5-26	13.7	.44	13.6	.33	-0.1
6-2	13.6	.38	13.6	.38	0.0
6-9	16.0	.56	15.1	.32	-0.9
6-16	14.9	.57	14.4	.42	-0.5
6-23			15.6	.51	
6-30	17.8	.22	18.6	.87	0.8
7-7	17.4	.21	17.9	.52	0.5
7-14	17.2	.06	18.2	.64	1.0 *
7-21	17.5	.06	18.3	.56	0.8
7-28	17.4	.11	18.1	.57	0.7
8-4			18.5	.63	
8-11			18.1	.33	
8-18			16.1	.26	
8-25			15.7	.31	
9-1			15.8	.25	
9-8	15.9	.31	17.2	.66	1.3 *
9-15	12.4	.46	12.9	.36	0.5
9-22	13.6	.42	14.7	.23	1.1 *
9-29	8.9	.56	9.1	.34	0.2
10-6	8.2	.42	8.4	.37	0.2
10-13	7.3	.56	7.3	.54	0.0
10-20	6.8	.63	6.6	.50	-0.2
10-27	7.0	.63	6.6	.47	-0.4
Wk 1-10					
12-16, 22-29	12.2	4.56	12.5	5.05	0.3

\* Denotes significant differences at 5%.

Table 8

Average Weekly Soil Temperature at 5 cm  
on the Control and Antenna Plantation

Mid Week Date	<u>Antenna</u>		<u>Control</u>		<u>Control- Antenna</u>
	Ave. C°	St.D	Ave. C°	St.D	Ave. C°
4-15			0.9	1.02	
4-22			10.1	1.71	
4-29			8.4	.45	
5-6			10.6	.12	
5-12	15.4	.72	14.6	.28	-0.8 *
5-19	13.4	.53	12.1	.04	-1.3 *
5-26	14.4	.74	13.5	.12	-0.9 *
6-2	13.9	.44	13.5	.28	-0.4
6-9	16.2	.50	15.0	.43	-1.2 *
6-16	15.3	.37	14.4	.36	-0.9 *
6-23	16.3	.61	15.8	.55	-0.5
6-30	19.3	.64	18.9	.74	-0.4
7-7	18.0	.50	18.0	.52	0.0
7-14	18.7	.56	18.2	.68	-0.5
7-21	18.8	.63	18.4	.51	-0.4
7-28	18.5	.52	17.9	.64	-0.6
8-4	19.0	.56	18.7	.79	-0.3
8-11	18.5	.58	18.1	.26	-0.4
8-18	15.8	.29	15.9	.23	0.1
8-25	16.0	.08	15.8	.22	-0.2
9-1	15.7	.20	15.8	.22	0.1
9-8	16.6	.24	16.6	.23	0.0
9-15	12.8	.86	12.7	.26	-0.1
9-22	13.7	.35	14.5	.22	0.8
9-29	8.7	.31	8.6	.21	-0.1
10-6	7.9	.28	8.1	.31	0.2
10-13	7.1	.24	7.0	.51	-0.1
10-20	6.8	.04	6.5	.41	-0.3
10-27	6.9	.08	6.5	.41	0.3
Wk 5-29	14.5	3.88	14.2	3.99	0.3

\* Denotes significant difference at 5% level.

Table 9

Average Weekly Soil Temperature at 10 cm  
in Control and Antenna Plantations

Mid Week Date	<u>Antenna</u>		<u>Control</u>		<u>Control- Antenna</u>	
	Ave. C°	St.D	Ave. C°	St.D	Ave. C°	
4-15			.2	.18		
4-22			5.6	2.12		
4-29			8.4	.93		
5-6			10.4	.23		
5-12	15.0	.82	14.2	.17	-0.8	*
5-19	13.1	.52	12.3	.48	-0.8	*
5-26	14.4	.62	13.6	.33	-0.8	*
6-2	13.7	.37	13.6	.38	-0.1	
6-9	15.9	.71	15.1	.32	-0.8	
6-16	15.1	.55	14.4	.42	-0.7	
6-23	15.5	.43	15.6	.51	-0.1	
6-30	18.8	.71	18.6	.87	-0.2	
7-7	18.0	.43	17.9	.52	-0.1	
7-14	18.4	.33	18.2	.64	-0.2	
7-21	18.4	.38	18.3	.56	-0.2	
7-28	18.3	.34	18.1	.57	-0.2	
8-4	18.6	.35	18.5	.63	-0.1	
8-11	18.0	.25	18.1	.33	0.1	
8-18	15.8	.27	16.1	.26	0.3	
8-25	15.6	.23	15.7	.31	0.1	
9-1	15.6	.26	15.8	.25	0.2	
9-8	16.5	.26	17.2	.66	0.7	*
9-15	12.8	.47	12.8	.36	0.0	
9-22	14.0	.27	14.7	.23	0.7	
9-29	8.9	.34	9.1	.34	0.2	
10-6	8.1	.25	8.4	.37	0.3	
10-13	7.2	.13	7.3	.54	0.1	
10-20	6.9	.10	6.6	.50	-0.3	
10-27	7.2	.15	6.6	.47	-0.6	
Wk 5-29	14.4	3.87	14.3	3.89	-0.1	

\* Denotes significant difference at 5% level.



Table 10

Average Weekly Soil Temperature at 5 cm  
in Control and Antenna Pole-Sized Tree Plots

Mid Week Date	<u>Ground</u>		<u>Control</u>		<u>Control- Antenna</u>
	Ave. C°	St.D	Ave. C°	St.D	Ave. C°
4-15					
4-22					
4-29					
5-6					
5-12	12.6	.88	11.9	.24	-0.7
5-19	9.9	.48	9.7	.20	-0.2
5-26	10.4	.67	10.7	.13	0.3
6-2	10.1	.61	10.4	.20	0.3
6-9	11.5	.79	11.8	.22	0.3
6-16	11.2	.59	11.3	.20	0.1
6-23	12.3	.50	12.9	.26	0.6
6-30	14.8	1.03	15.3	.22	0.5
7-7	14.8	.76	15.1	.20	0.3
7-14	14.9	.94	15.5	.21	0.4
7-21	15.4	.70	15.9	.18	0.5
7-28	15.0	1.17	15.8	.20	0.8
8-4	15.4	2.02	16.7	.08	1.3
8-11	15.8	1.06	16.3	.18	1.5
8-18	13.3	1.59	14.4	.29	1.1
8-25	13.4	1.20	14.4	.12	1.0
9-1	13.4	1.18	14.5	.14	0.9
9-8	14.6	.93	15.6	.10	1.0
9-15	10.0	2.48	12.3	.22	2.3 *
9-22	11.9	1.67	13.7	.14	1.8 *
9-29	6.5	2.48	8.3	.40	1.8 *
10-6	6.4	2.26	7.9	.17	1.5
10-13	6.9	.21	7.0	.08	0.1
10-20	6.4	.64	7.3	.09	0.9
10-27	5.9	1.69	7.4	.06	1.5
Wk 1-29	11.7	3.23	12.5	3.15	0.8

\* Denotes significant difference between sites for a given week.

Table 11

Average Weekly Soil Temperature at 10 cm  
in Control and Antenna Pole-Sized Tree Plots

Mid Week Date	<u>Ground</u>		<u>Control</u>		<u>Control- Antenna</u>
	Ave. C°	St.D	Ave. C°	St.D	Ave. C°
4-15					
4-22					
4-29					
5-6					
5-12	11.9	.64	11.3	.15	-0.6
5-19	9.7	.45	9.6	.26	-0.1
5-26	10.1	.50	10.5	.20	0.4
6-2	9.7	.37	10.1	.17	0.4
6-9	11.2	.45	11.5	.22	0.3
6-16	10.8	2.60	11.1	.19	
6-23	11.9	.33	12.4	.22	0.5
6-30	14.3	.69	14.7	.29	0.4
7-7	14.3	.67	14.8	.28	0.5
7-14	14.4	.69	15.1	.28	0.7
7-21	14.8	.59	15.5	.28	0.7
7-28	14.9	.59	15.5	.25	0.6
8-4	15.5	.67	16.1	.45	0.6
8-11	15.6	.50	16.1	.21	0.6
8-18	13.9	.48	14.4	.26	0.6
8-25	13.4	.35	14.3	.15	0.9
9-1	13.6	.50	14.5	.12	0.9
9-8	14.6	.56	15.6	.10	1.0
9-15	11.1	.79	12.4	.18	1.3 *
9-22	12.6	.62	13.9	.13	1.3 *
9-29	8.3	.82	8.8	.37	0.5
10-6	7.8	.71	8.2	.17	0.4
10-13	7.0	.81	7.4	.08	0.4
10-20	6.8	.77	7.4	.08	0.6
10-27	6.9	.75	7.6	.15	0.7
Wk 5-29	11.9	2.87	12.3	2.98	0.4

\* Denotes significant difference at 5% level.

Table 12

Average Weekly Soil Moisture  
At 5 cm on Control and Ground Sites Plantations

Mid-Week Date	<u>Ground</u>		<u>Control</u>		<u>Control- Ground</u>	
	Ave. %	St.D	Ave. %	St.D	Ave. %	
4-15	13.7		7.9	1.10	-5.8	*
4-22	9.7		8.0	3.35	-1.7	
4-29	9.2		5.8	1.26	-3.4	
5-6	10.5		10.0	2.13	-0.5	
5-12	11.8	.98	11.3	2.25	-0.5	
5-19	12.3	1.41	11.0	2.34	-0.5	
5-26	12.6	1.56	11.2	2.51	-0.4	
6-2	12.8	1.56	11.1	2.33	-1.7	
6-9	13.3	1.98	11.3	2.32	2.0	
6-16	12.0	1.78	12.1	2.96	0.1	
6-23			12.2	3.04		
6-30	9.3	.31	11.7	3.20	2.4	
7-7	11.0	.61	11.9	2.43	0.9	
7-14	9.1	.95	10.3	3.76	1.2	
7-21	7.5	.57	9.3	3.72	1.8	
7-28	9.3	.91	9.1	2.50	-0.2	
8-4	6.5	.15	7.6	2.10	1.1	
8-11			10.8	1.71		
8-18			10.3	1.95		
8-25			11.1	1.81		
9-1			11.4	1.90		
9-8	11.6	.15	11.8	1.93	0.2	
9-15	10.4	.25	10.7	2.16	0.3	
9-22	11.1	.10	11.2	1.54	0.1	
9-29	11.0	.00	10.5	1.80	-0.5	
10-6	10.7	.20	10.4	1.76	-0.3	
10-13	10.4	.12	10.1	1.78	-0.3	
10-20	9.6	.40	9.8	1.77	0.2	
10-27	9.5	.98	9.7	1.45	0.2	
Wk 1-10						
12-17, 22-29	10.6	1.73	10.2	1.57	0.4	

\* Denotes significant difference at 5% level.

Table 13

Average Weekly Soil Moisture at 10 cm  
on the Ground and Control Plantations

Mid Week Date	<u>Ground</u>		<u>Control</u>		<u>Control- Ground</u>
	Ave. C°	St.D	Ave. C°	St.D	Ave. C°
4-15	9.1	2.69	7.0		-2.1
4-22	9.7	1.34	9.8		0.1
4-29	8.5	1.80	6.6	2.05	-1.9
5-6	7.7	2.17	8.8	1.01	1.1
5-12	8.8	1.17	10.5	.71	1.7
5-19	9.1	1.65	10.6	.74	1.5
5-26	9.4	2.0	11.0	.55	1.6
6-2	10.0	1.96	10.8	.55	0.8
6-9	10.3	2.01	10.8	.65	0.5
6-16	9.8	1.15	10.6	.72	0.8
6-23			10.7	.64	
6-30	8.8	1.20	10.5	.78	1.7
7-7	9.5	.76	10.8	.38	1.3
7-14	8.8	1.30	9.6	1.05	1.2
7-21	8.1	1.83	8.4	1.55	0.3
7-28	8.8	1.46	8.1	1.17	-0.7
8-4	8.1	2.02	6.8	1.25	1.3
8-11			9.7	.65	
8-18			9.1	.89	
8-25			9.5	1.27	
9-1			10.0	.80	
9-8	10.0	.47	10.7	.38	0.7
9-15	9.4	.85	9.5	.92	0.1
9-22	9.6	.71	10.0	.53	0.4
9-29	9.7	.72	9.4	.91	-0.3
10-6	9.5	.78	9.2	.70	-0.3
10-13	9.2	.49	9.0	.76	-0.2
10-20	9.8	1.43	8.4	.47	-1.4
10-27	9.7	2.08	8.1	.47	-1.6
Wk 1-10, 12-17, 22-29	9.2	.67	9.4	1.35	0.2

\* Denotes significant difference at 5% level.

Table 14

Average Weekly Soil Moisture at 5 cm  
in Control and Antenna Plantations

Mid Week Date	<u>Ground</u>		<u>Control</u>		<u>Control- Antenna</u>
	Ave. %	St.D	Ave. %	St.D	Ave. %
4-15			7.9	1.10	
4-22			8.05	3.35	
4-29			5.8	1.26	
5-6	7.6	2.75	10.0	2.13	2.4
5-12	9.1	1.37	11.3	2.25	2.4
5-19	8.7	1.56	11.0	2.34	2.3
5-26	8.9	.92	11.2	2.51	2.3
6-2	8.7	1.13	11.1	2.33	2.4
6-9	8.4	1.20	11.3	2.32	2.9
6-16	7.7	1.48	12.1	2.96	4.4
6-23	7.5	1.41	12.2	3.04	4.7
6-30	5.8	.57	11.7	3.20	5.9 *
7-7	7.0	.99	11.9	2.43	4.9 *
7-14	5.2	.85	10.3	3.76	5.1 *
7-21	5.1	.28	9.3	3.72	4.2
7-28	6.2	1.70	9.1	2.50	2.9
8-4	5.8	.70	7.6	2.10	1.8
8-11	6.0	.92	10.8	1.71	4.8 *
8-18	6.0	.63	10.3	1.95	4.3
8-25	8.6		11.1	1.81	2.5
9-1	7.1	1.63	11.4	1.90	4.3
9-8	7.5	1.84	11.8	1.93	4.3
9-15	6.3	1.20	10.7	2.16	4.4
9-22	6.7	1.56	11.2	1.54	4.5
9-29	7.4	1.56	10.5	1.80	3.1
10-6	7.4	1.62	10.4	1.76	3.0
10-13	6.9	1.41	10.1	1.78	3.2
10-20	6.2	1.41	9.8	1.77	3.6
10-27	6.1	1.41	9.7	1.45	3.6
Wk 4-29	7.1	1.17	10.7	1.04	3.6

\* Denotes significant difference at 5% level.

Table 15

Average Weekly Soil Moisture at 10 cm  
in Control and Antenna Plantations

Mid Week Date	<u>Ground</u>		<u>Control</u>		<u>Control- Antenna</u>
	Ave. %	St.D	Ave. %	St.D	Ave. %
4-15			7.0		
4-22			9.8		
4-29			6.6	2.05	
5-6	7.5	2.76	8.8	1.00	1.3
5-12	8.1	2.12	10.5	.71	2.4
5-19	8.2	1.86	10.6	.73	2.4
5-26	8.4	1.83	11.0	.55	2.6
6-2	8.2	1.80	10.8	.55	2.6
6-9	8.3	2.00	10.8	.65	2.5
6-16	8.0	1.85	10.6	.72	2.6
6-23	7.7	1.80	10.7	.64	3.0
6-30	6.7	2.00	10.5	.78	3.8 *
7-7	7.0	2.17	10.8	.38	3.8 *
7-14	5.7	2.93	9.6	1.05	3.9 *
7-21	5.2	2.42	8.4	1.55	3.2
7-28	5.9	2.99	8.1	1.17	2.2
8-4	5.7	2.51	6.8	1.25	1.1
8-11	7.0	2.11	9.7	.65	2.7
8-18	6.9	2.11	9.1	.88	2.2
8-25	7.1	2.00	9.5	1.30	2.4
9-1	6.7	2.05	10.0	.80	3.3
9-8	7.1	2.04	10.7	.38	3.6 *
9-15	6.4	1.75	9.5	.92	3.1
9-22	6.9	2.12	10.0	.53	3.1
9-29	6.9	2.20	9.4	.91	2.5
10-6	6.8	2.14	9.2	.70	2.4
10-13	6.7	2.30	9.0	.76	2.3
10-20	6.3	2.46	8.4	.60	2.1
10-27	5.9	1.96	8.1	.47	2.2
Wk 4-29	7.0	.89	9.6	1.07	2.6

\* Denotes significant difference at 5% level.

Table 16

Average Weekly Soil Moisture at 5 cm  
in Control and Antenna Pole-Sized Tree Plots

Mid Week Date	<u>Antenna</u>		<u>Control</u>		<u>Control-</u>
	Ave. %	St.D	Ave. %	St.D	Ave. %
4-15					
4-22					
4-29					
5-6	7.8	1.83	6.5	.07	-1.3
5-12	6.7	1.91	7.3	2.40	0.6
5-19	6.8	2.04	8.0	2.09	1.2
5-26	6.8	2.31	8.2	1.77	1.4
6-2	7.2	2.12	8.3	1.44	1.1
6-9	7.0	2.02	8.7	1.48	1.7
6-16	6.7	2.05	8.7	1.45	2.0
6-23	6.6	2.36	8.6	2.10	2.0
6-30	5.3	1.60	8.7	2.21	3.4
7-7	6.1	1.51	7.1	3.20	1.1
7-14	5.3	1.96	8.2	2.45	2.9
7-21	4.7	1.00	5.5	3.01	1.8
7-28	5.7	.90	4.1	2.37	-1.6
8-4	5.2	.92	4.20	1.65	-1.0
8-11	6.4	1.30	3.8	1.48	-2.6
8-18	6.6	1.20	7.1	.92	0.5
8-25	6.0	.29	6.0	1.26	0.0
9-1	6.9	1.54	7.6	1.50	.7
9-8	7.1	1.8	8.2	1.35	1.1
9-15	6.5	1.32	9.9	.95	3.4
9-22	6.7	1.31	8.1	2.20	1.4
9-29	6.7	1.51	8.6	2.16	1.9
10-6	6.6	1.41	8.7	1.80	2.1
10-13	6.5	1.40	8.5	1.99	2.0
10-20	6.3	.81	8.0	2.34	2.7
10-27	6.8	.58	8.1	2.43	7.3
Wk 4-29	6.4	.69	7.6	1.58	1.2

Table 17

Average Weekly Soil Moisture at 10 cm  
in Control and Antenna Pole-Sized Tree Plots

Mid Week Date	<u>Antenna</u>		<u>Control</u>		<u>Control- Antenna</u>	
	Ave. %	St.D	Ave. %	St.D	Ave. %	
4-15			10.1	0.0		
4-22			7.6	2.26		
4-29			7.8	1.51		
5-6	4.2	1.65	15.7	.61	-1.5	
5-12	4.2	1.77	6.9	.35	2.7	*
5-19	4.3	1.86	7.0	.50	2.7	*
5-26	4.2	1.63	7.7	.60	2.9	*
6-2	4.4	1.85	7.5	.62	3.1	*
6-9	4.1	1.70	7.4	.75	3.3	*
6-16	3.7	1.46	7.2	.74	3.5	*
6-23	4.0	1.69	7.1	.79	3.1	*
6-30	3.2	1.05	6.8	.87	3.6	*
7-7	4.4	.73	7.1	.72	2.7	*
7-14	3.4	1.1	5.5	.83	2.1	*
7-21	3.1	.74	4.0	.86	1.9	
7-28	4.0	1.18	4.3	.30	0.3	
8-4	3.3	1.14	3.6	.30	0.3	
8-11	4.3	.35	6.2	.90	1.9	
8-18	4.4	.68	5.8	.60	1.4	
8-25	5.0	.83	6.6	.36	1.6	
9-1	4.9	.70	7.1	.35	2.2	*
9-8	5.2	.57	8.3	.42	3.1	*
9-15	4.3	.57	7.1	.65	2.8	*
9-22	4.5	.55	7.6	.78	3.1	*
9-29	4.7	1.0	7.6	.46	1.9	*
10-6	4.5	1.08	7.3	.66	2.8	*
10-13	4.3	.98	7.3	.60	3.0	*
10-20	3.7	1.25	7.0	.67	3.3	*
10-27	3.8	1.08	6.9	.80	3.1	*
Wk 1-29	4.2	.53	6.6	1.15	2.4	

\* Denotes significant difference at 5% level.



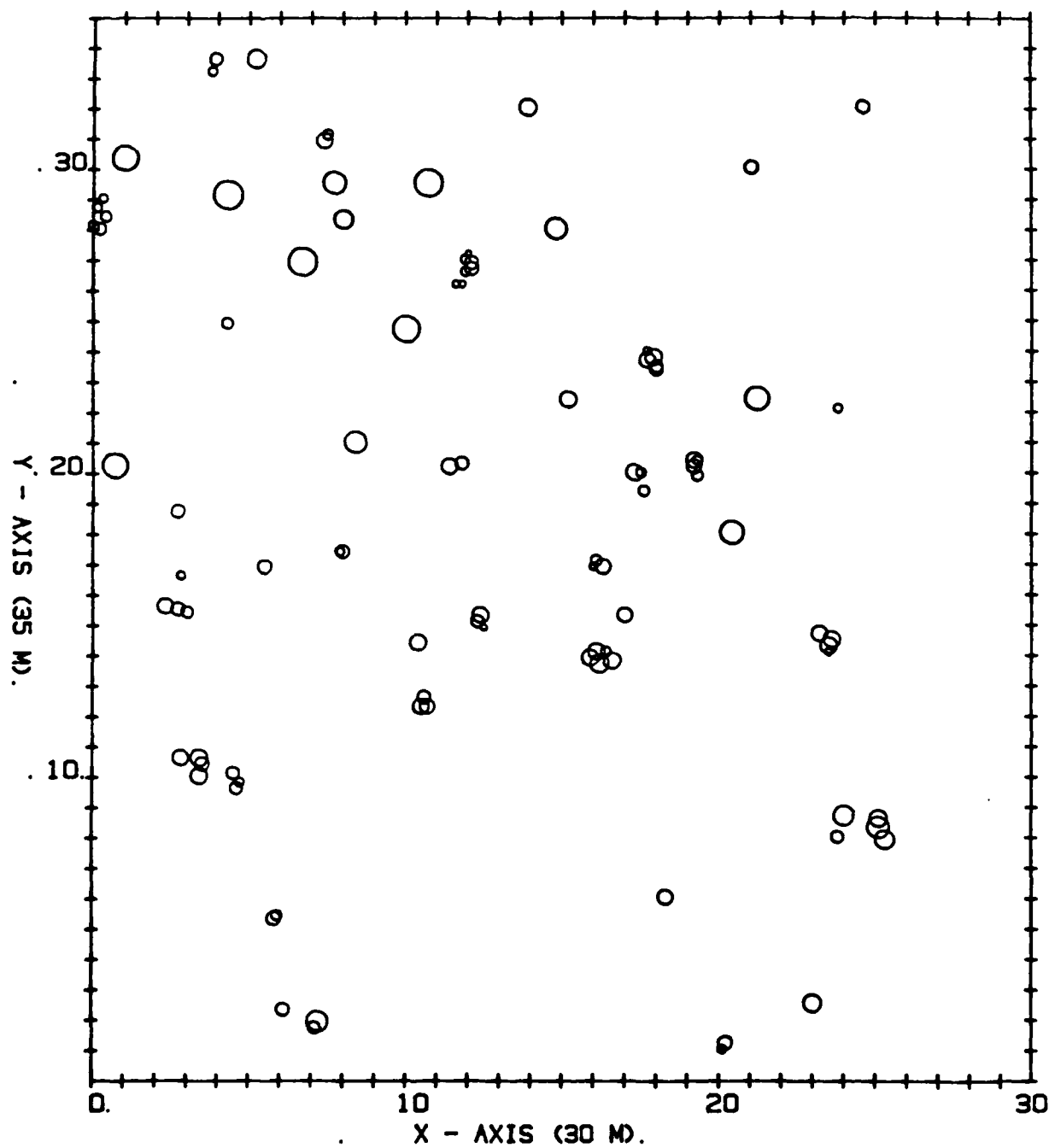
#### APPENDIX C

##### Polesized Stand Plot Maps Developed From Plot Mapping Coordinates

NOTE: The maps in this section are color coded and were not reproducible by ordinary duplicating techniques. For a set of color originals write to:

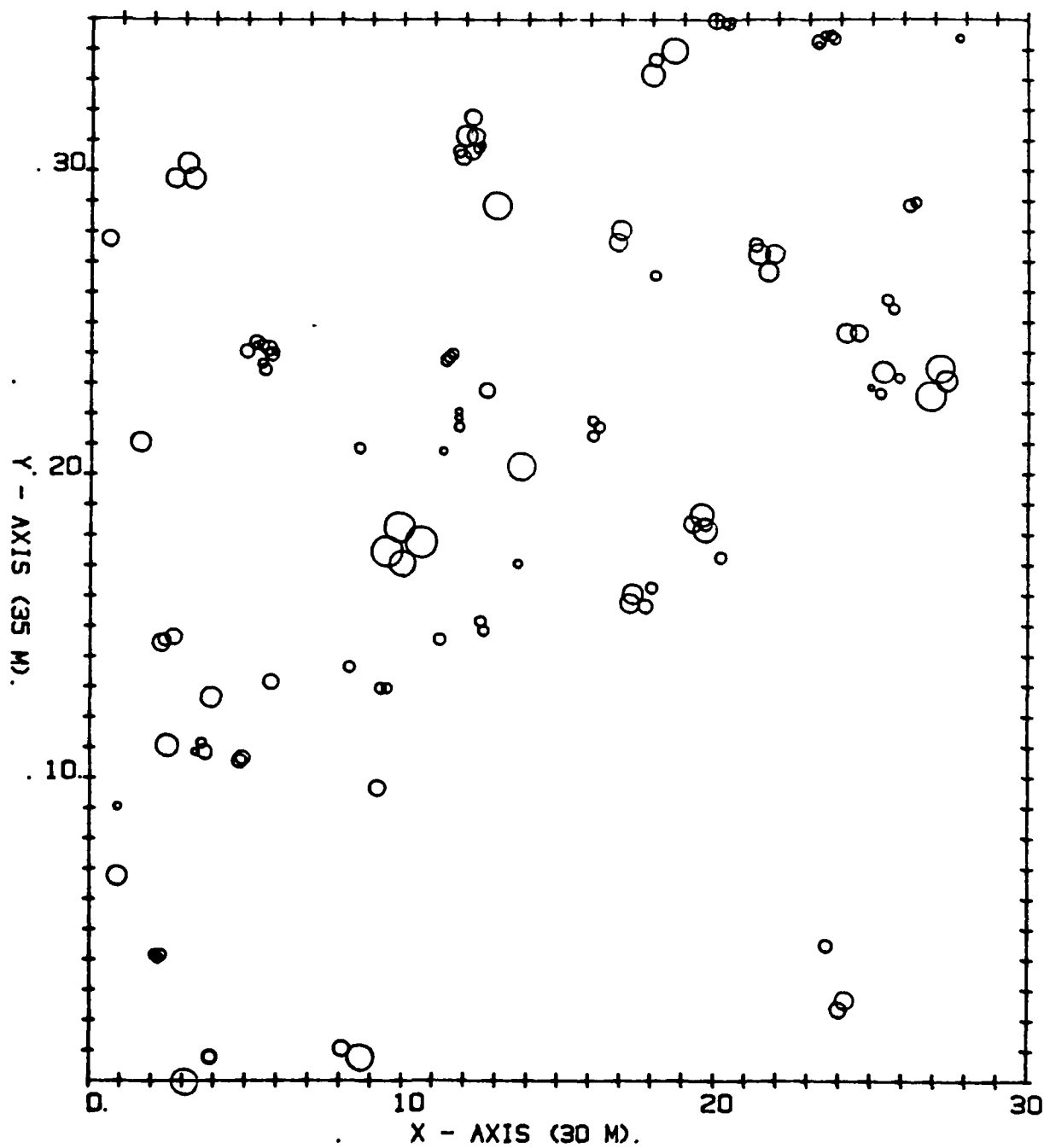
Glenn Mroz  
School of Forestry and Wood Products  
Michigan Technological University  
Houghton, Michigan 49931

## . ELF ANTENNA - PLOT 1.

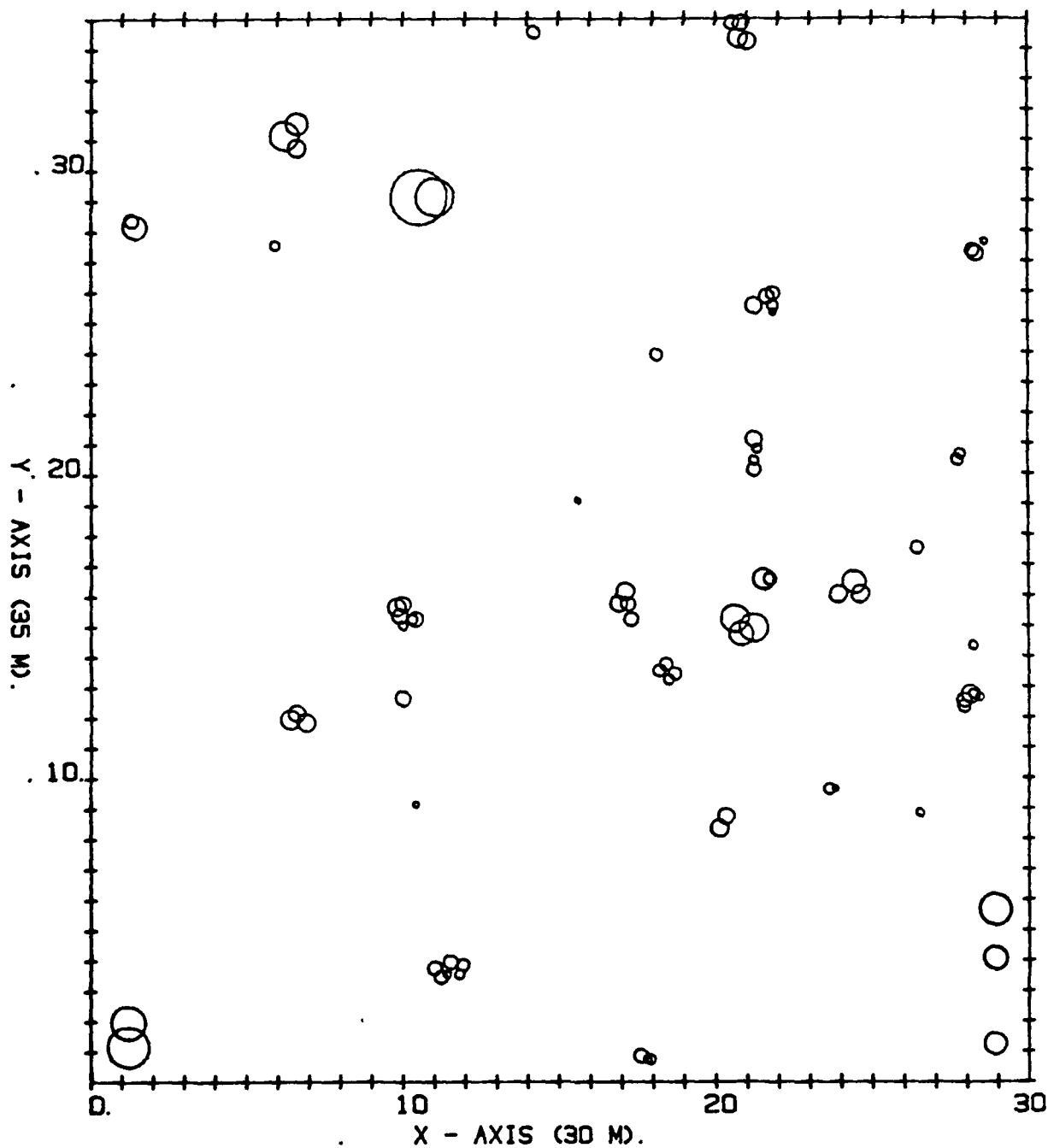


. GREEN = NRO, BLUE = PB, ORANGE = BTA, RED = RM, VIOLET = QA..

## . ELF ANTENNA - PLOT 2.

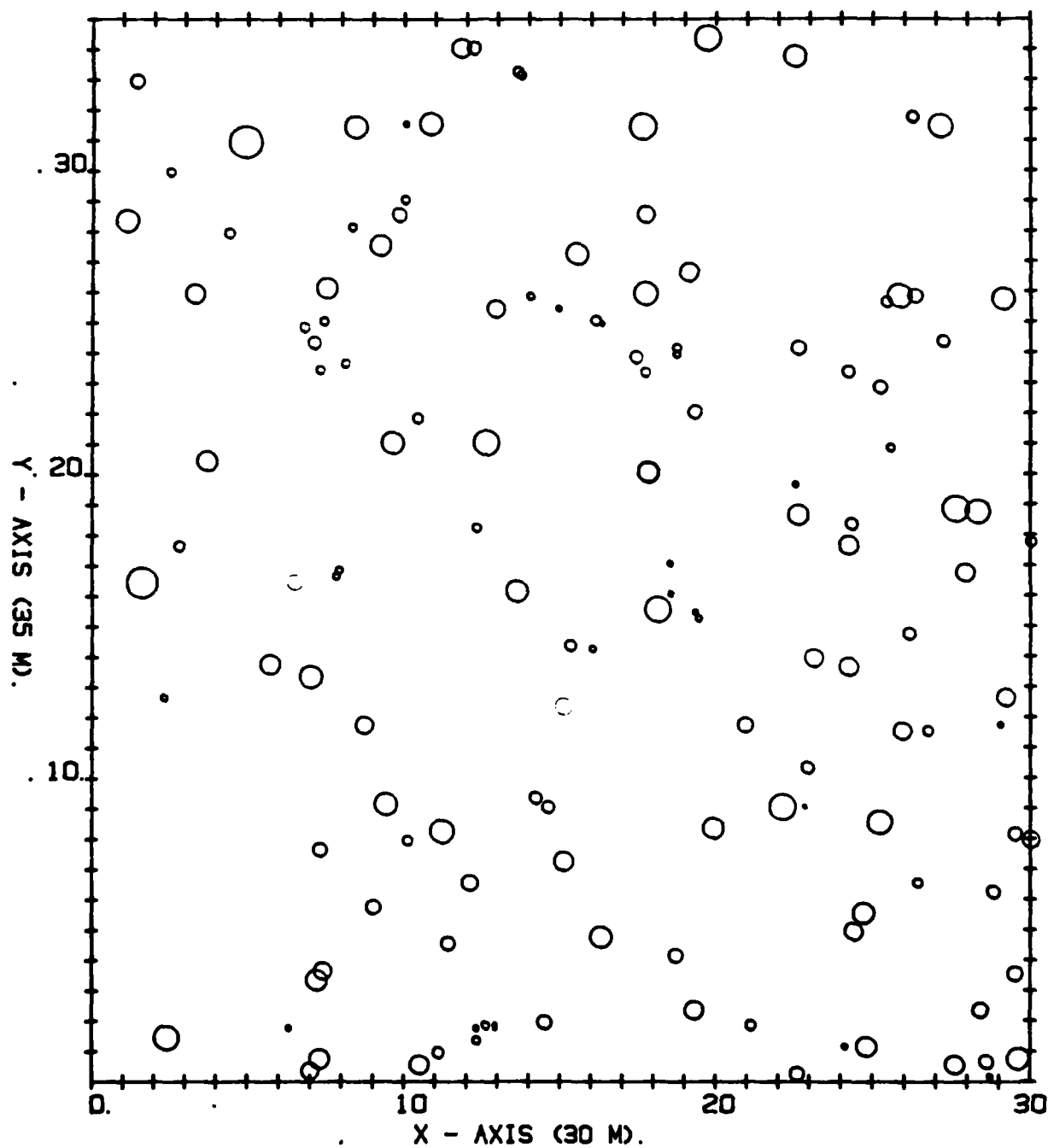


## . ELF ANTENNA - PLOT 3.



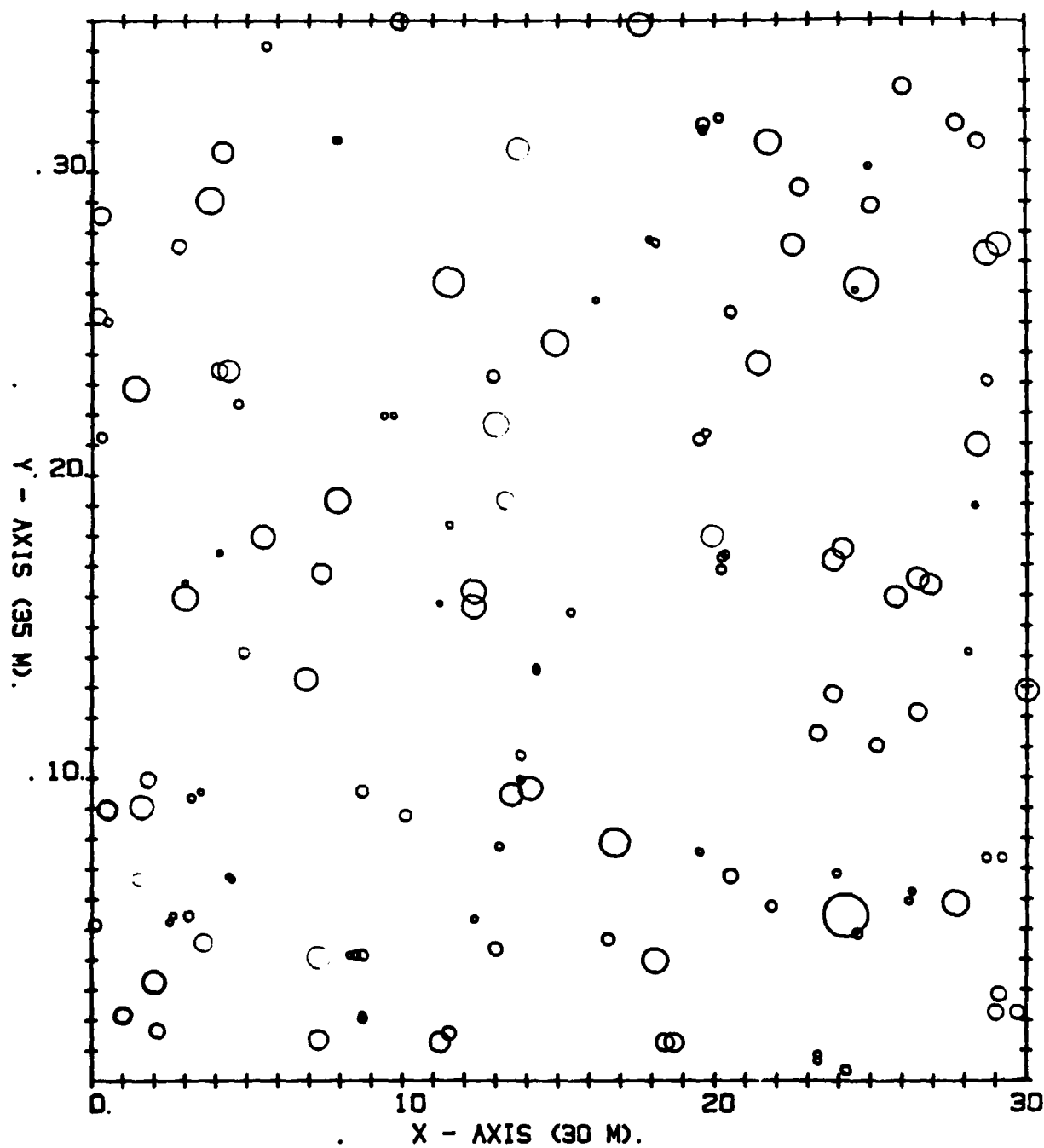
. GREEN = NRO, BLUE = PB, ORANGE = BTA, RED = RM, VIOLET = QA..

## . ELF CONTROL - PLOT 1.



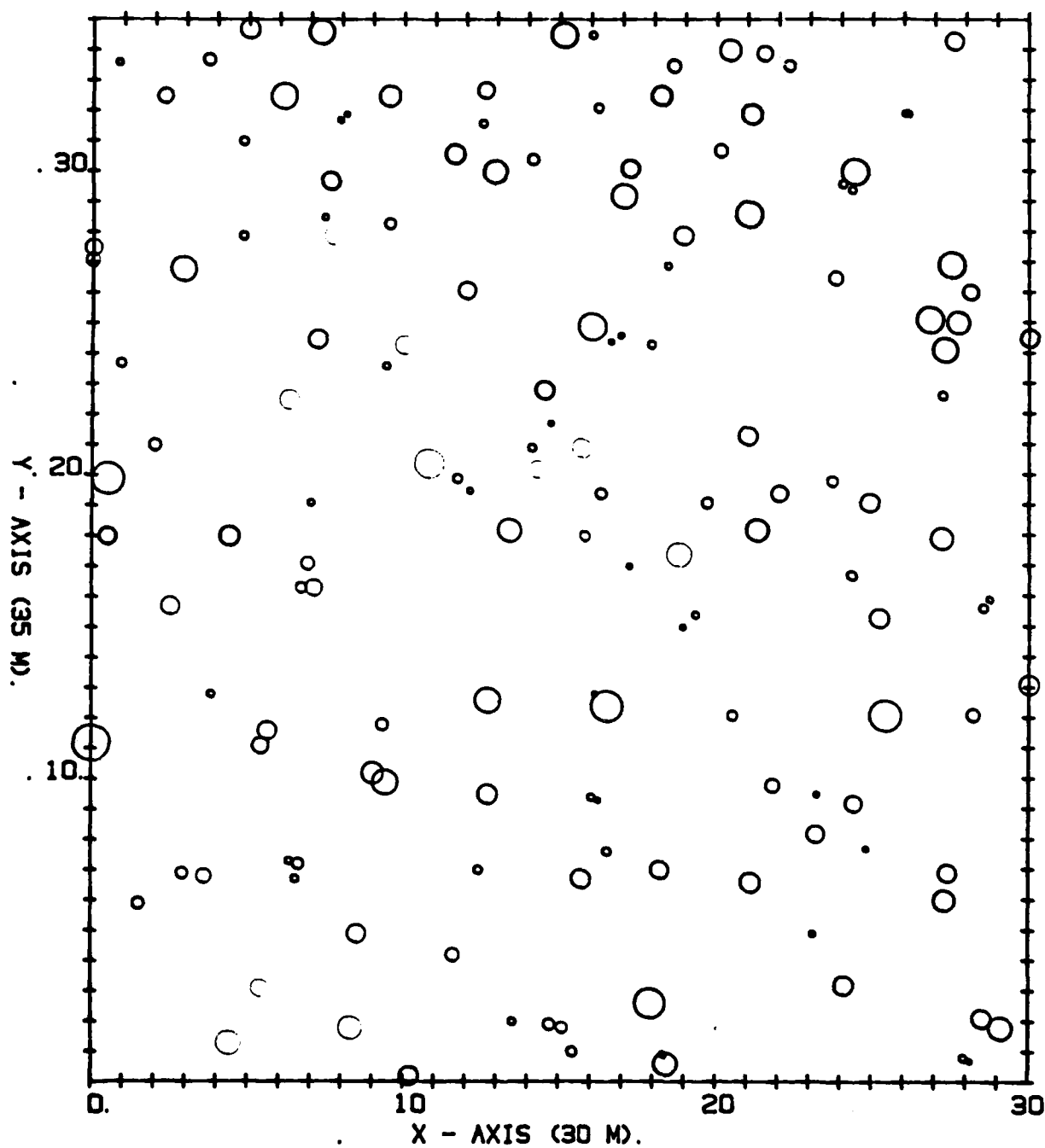
. GREEN = NRO, BLUE = PB, ORANGE = BTA, RED = RM, VIOLET = QA..

## . ELF CONTROL - PLOT 2.



. GREEN = NRO. BLUE = PB. ORANGE = BTA. RED = RM. VIOLET = QA..

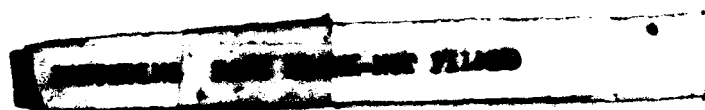
## . ELF CONTROL - PLOT 3.



. GREEN = NRO, BLUE = PB, ORANGE = BTA, RED = RM, VIOLET = QA..

## APPENDIX D

Average Incremental Diameter Growth By  
Week for Each Species and Each Diameter Class





# PAPER BIRCH - 1985

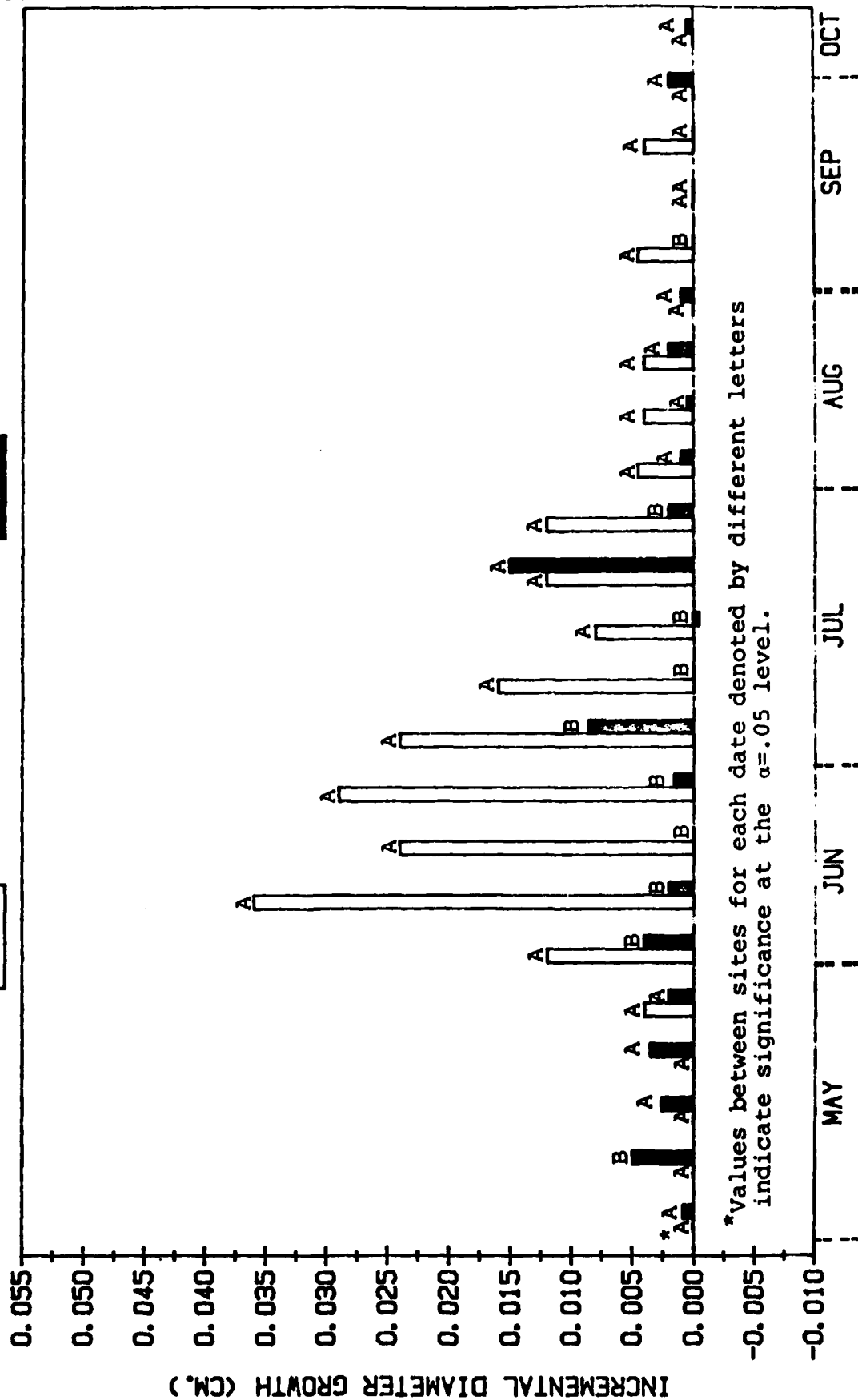
INCREMENTAL GROWTH FOR 10.0 - 14.9 CM. DIAMETER CLASS

MAY 1 - OCT 10

ANTENNA



CONTROL



# PAPER BIRCH - 1985

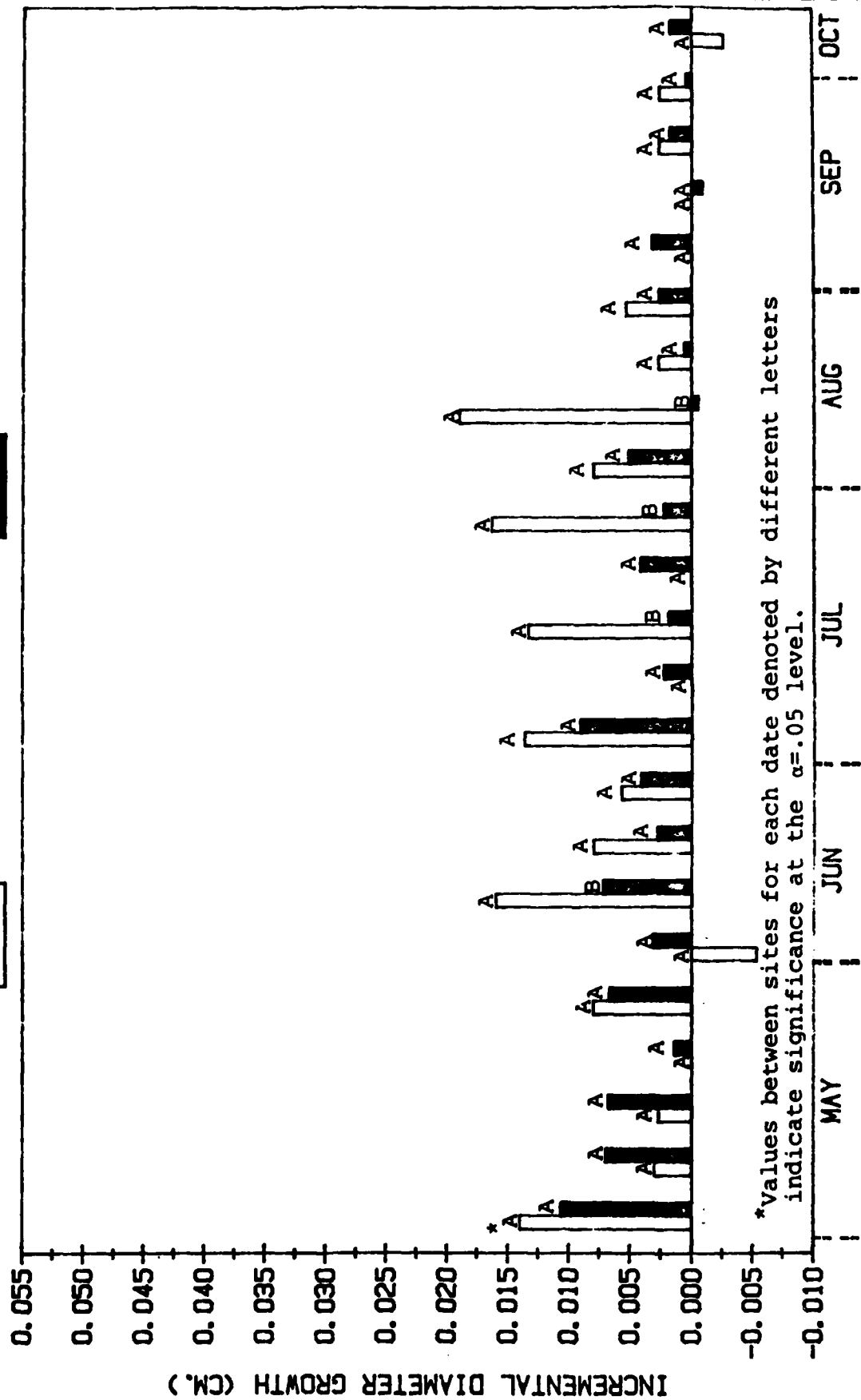
INCREMENTAL GROWTH FOR 15.0 - 19.9 CM. DIAMETER CLASS

MAY 1 - OCT 10

ANTENNA



CONTROL



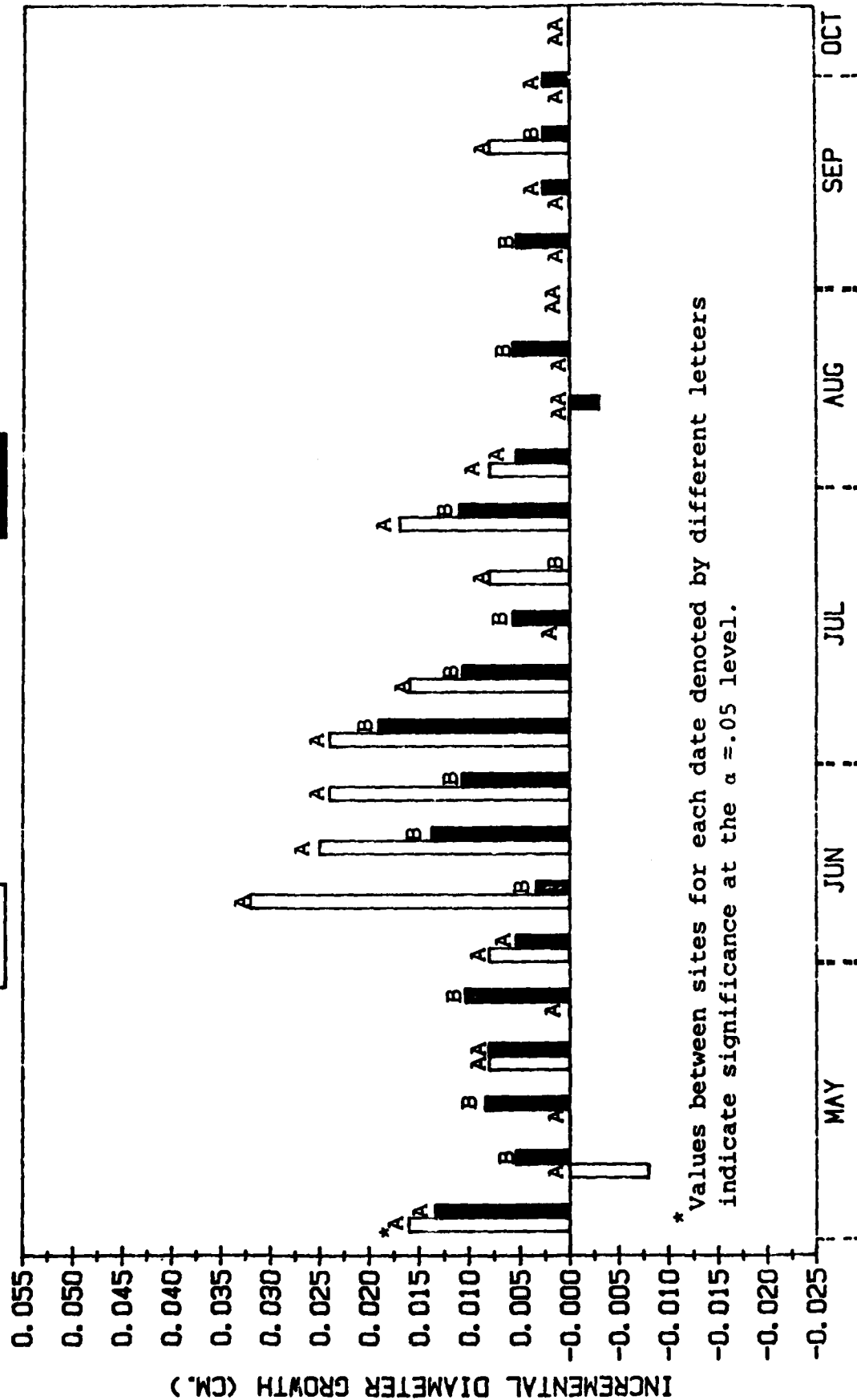
# PAPER BIRCH - 1985

INCREMENTAL GROWTH FOR 20.0 - 24.9 CM. DIAMETER CLASS

MAY 1 - OCT 10

ANTENNA

CONTROL



# PAPER BIRCH - 1985

INCREMENTAL GROWTH FOR 25.0 - 29.9 CM. DIAMETER CLASS

MAY 1 - OCT 10

ANTENNA

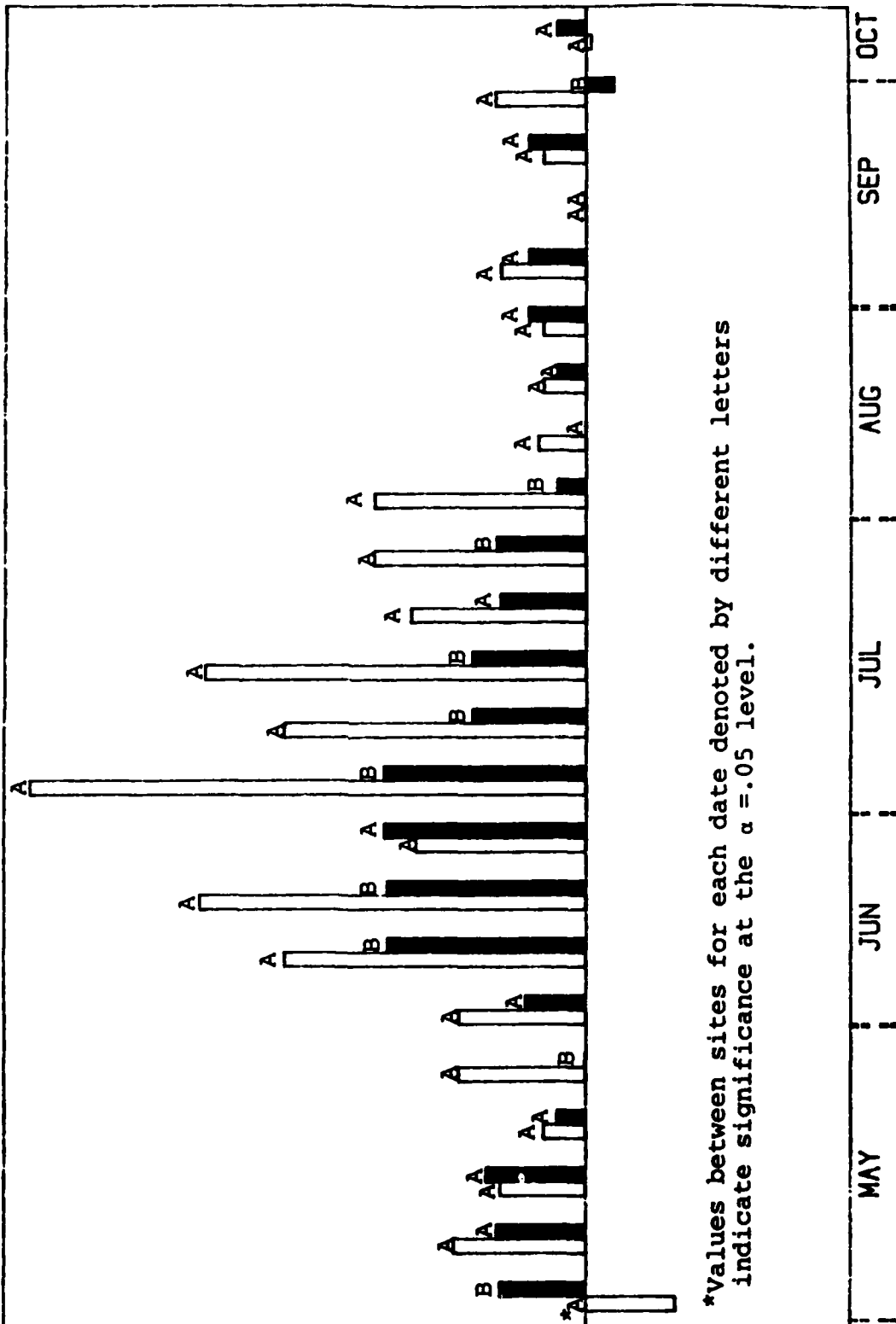


CONTROL



INCREMENTAL DIAMETER GROWTH (CM.)

0.055  
0.050  
0.045  
0.040  
0.035  
0.030  
0.025  
0.020  
0.015  
0.010  
0.005  
-0.000  
-0.005  
-0.010  
-0.015  
-0.020  
-0.025

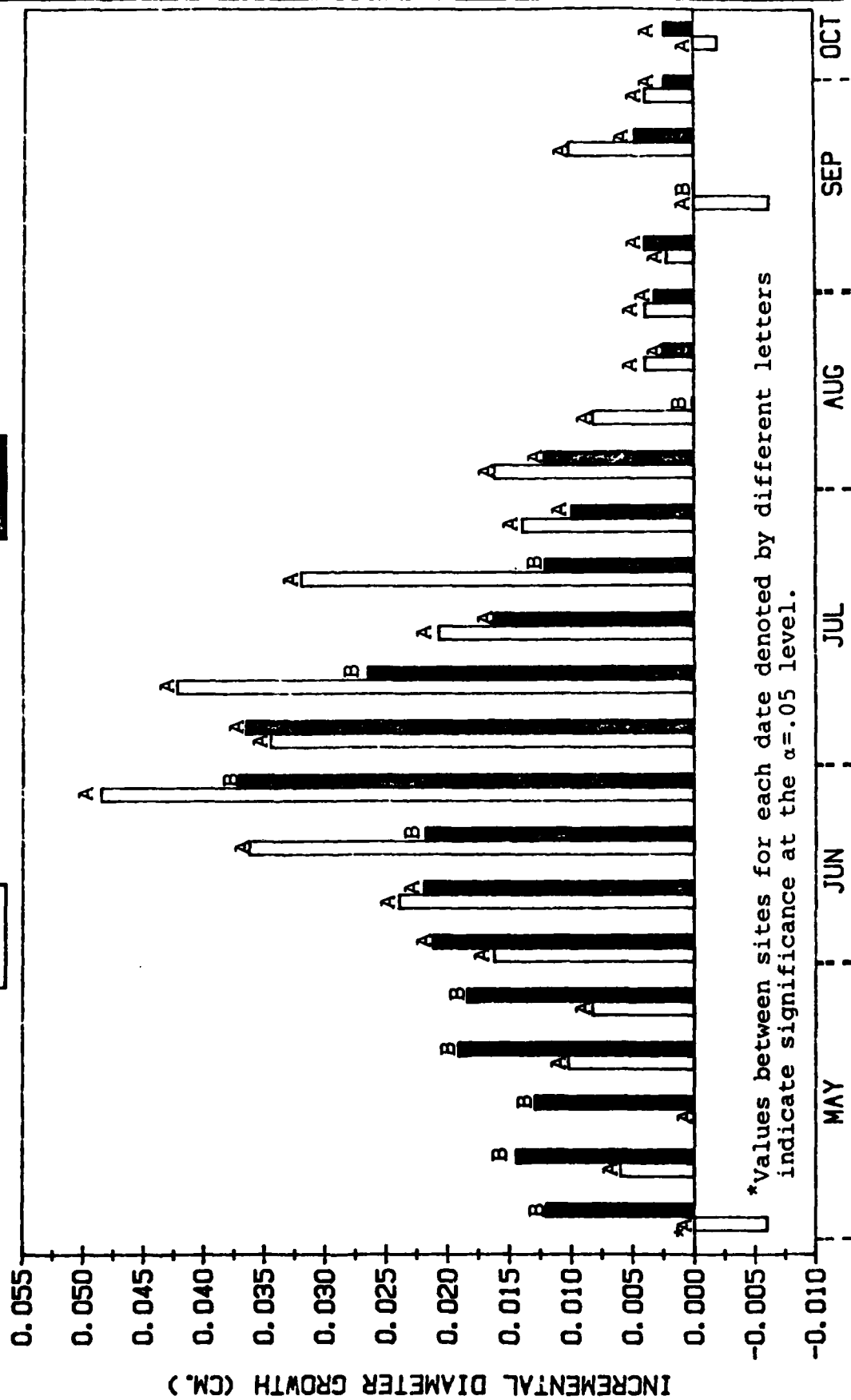


\*Values between sites for each date denoted by different letters indicate significance at the  $\alpha = 0.05$  level.

# **BIG TOOTH ASPEN - 1985** **INCREMENTAL GROWTH FOR 20.0 - 24.9 CM. DIAMETER CLASS** **MAY 1 - OCT 10**

ANTENNA

CONTROL



# BIG TOOTH ASPEN - 1985

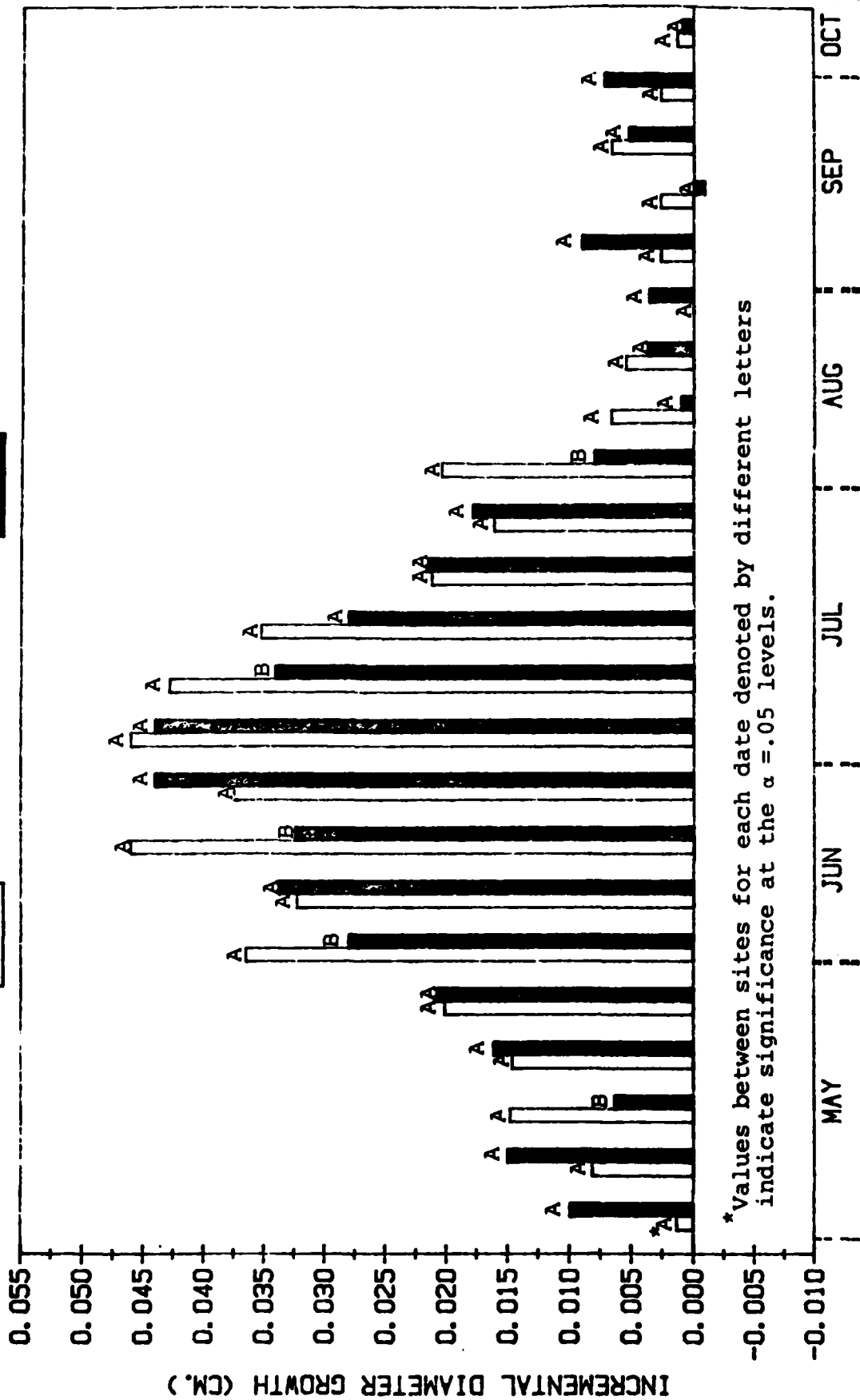
INCREMENTAL GROWTH FOR 25.0 - 29.9 CM. DIAMETER CLASS

MAY 1 - OCT 10

ANTENNA



CONTROL



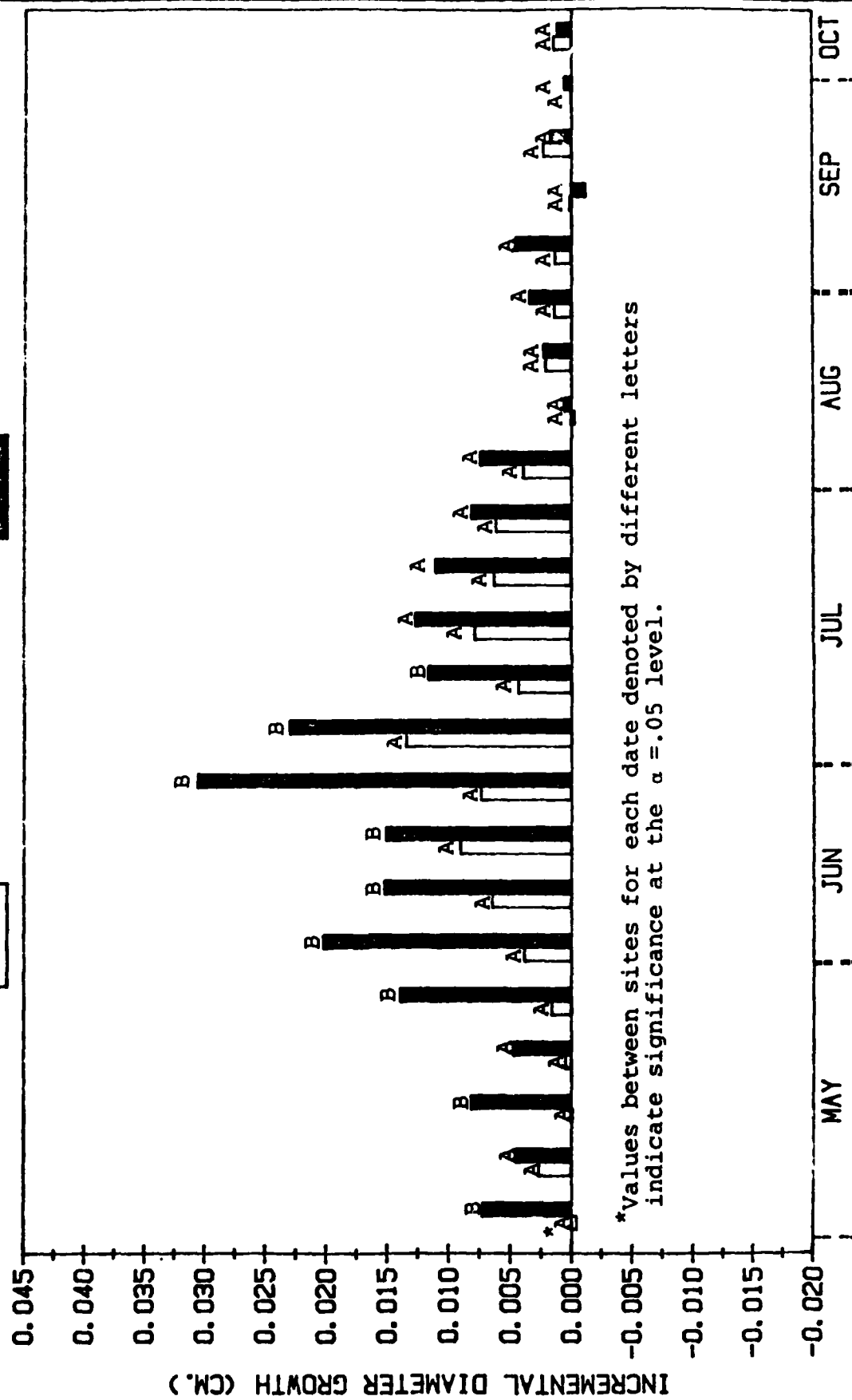
# RED MAPLE - 1985

## INCREMENTAL GROWTH FOR 10.0 - 14.9 CM. DIAMETER CLASS

### MAY 1 - OCT 10

ANTENNA 

CONTROL 

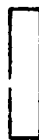


# RED MAPLE - 1985

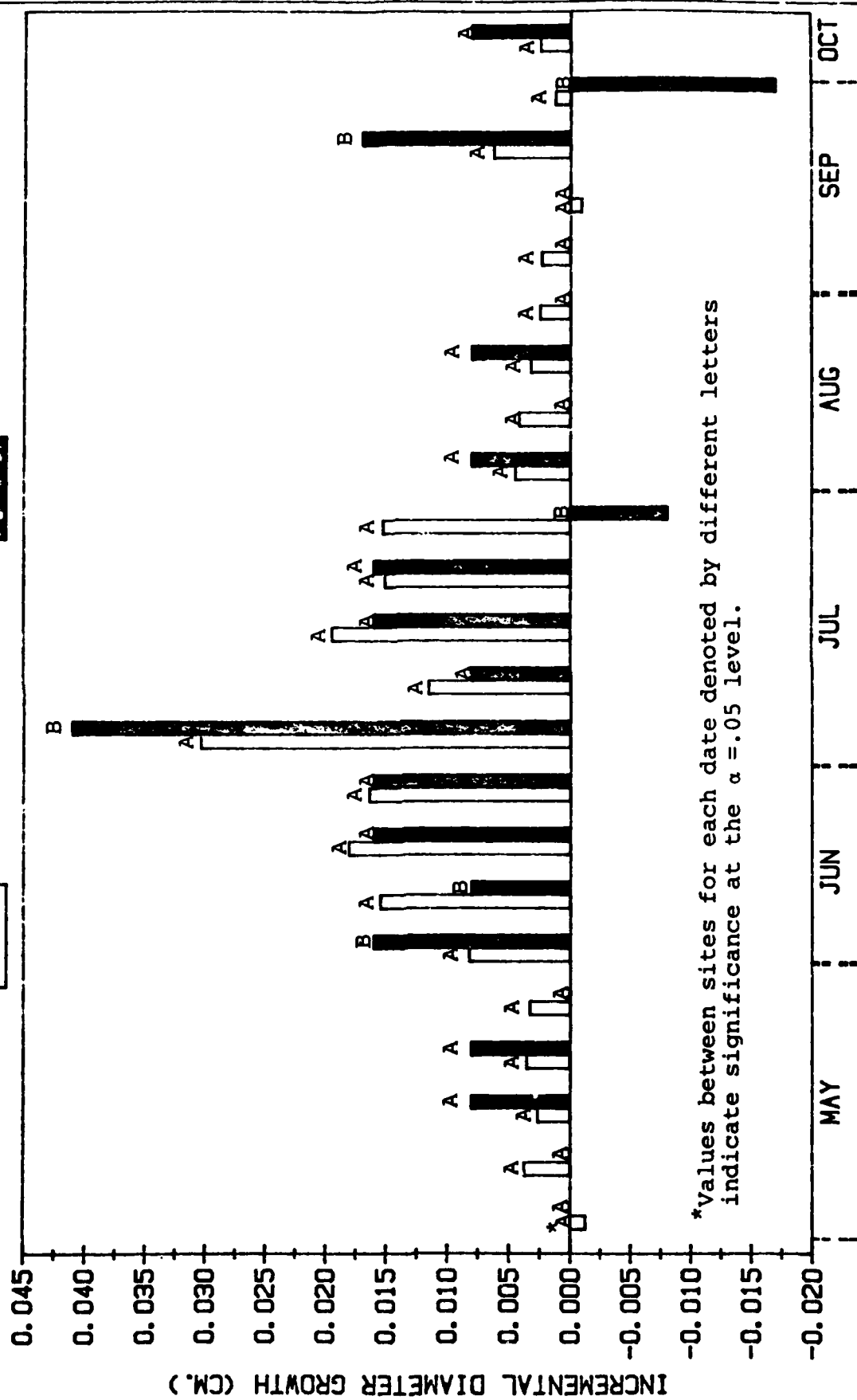
INCREMENTAL GROWTH FOR 15.0 - 19.9 CM. DIAMETER CLASS

MAY 1 - OCT 10

ANTENNA



CONTROL

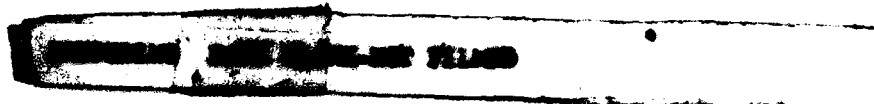


\*Values between sites for each date denoted by different letters indicate significance at the  $\alpha = .05$  level.



APPENDIX E

Diameter Growth Models Used in Comparison  
Analysis to Observed Diameter Growth



## U.S.D.A. General Forest Growth Model and Coefficients

$$\frac{\delta D}{\delta t} = b_1 + b_2 D^{b_3} + b_4 SI CR D^{b_5}$$

where

D = tree diameter  
 CR = tree crown ratio  
 SI = plot site index

Species	$b_1$	$b_2$	$b_3$	$b_4$	$b_5$	$R^2$
NRO	.098793	-.0000002	3.3873	.000080	.41156	.38
PB	.075650	-.0005900	2.0175	.000050	1.00030	.48
BTA	.141200	-.0002900	2.1217	.000030	1.00000	.28
RM	.067930	-.0003800	1.5944	.000200	.29971	.44
QA	.117890	-.0001500	2.3618	.000042	1.00000	.39

NRO = Northern Red Oak  
 PB = Paper Birch  
 BTA = Big Tooth Aspen  
 RM = Red Maple  
 QA = Quaking Aspen

## JABOWA and FORET Model, Modifiers, and Coefficients

## Optimum Diameter Growth Model:

$$\frac{\delta D}{\delta t} = \frac{GD(1 - DH/D_{MAX} H_{MAX})}{(274 + 3b_2D - 4b_3D^2)}$$

where

G = growth constant

D = tree diameter

H = tree height

$D_{MAX}$  = maximum obtainable diameter

$H_{MAX}$  = maximum obtainable height

## Modified Growth Model:

$$\frac{\delta D}{\delta t} = (\text{Optimum Growth})(T(\text{DEGD}))(S(\text{BAR}))(R(\text{AL}))$$

where

$T(\text{DEGD})$  = growing degree day modifier

$S(\text{BAR})$  = stand biomass modifier

$R(\text{AL})$  = available light modifier

Growing Degree Day Modifier:

$$T(\text{DEGD}) = \frac{4(\text{DEGD} - \text{DEGD}_{\text{MIN}})(\text{DEGD}_{\text{MAX}} - \text{DEGD})}{(\text{DEGD}_{\text{MAX}} - \text{DEGD}_{\text{MIN}})^2}$$

where

$$\text{DEGD} = \frac{365}{2\pi}(\text{T}_{\text{JUL}} - \text{T}_{\text{JAN}}) - \frac{365}{2}\left(40 - \frac{(\text{T}_{\text{JUL}} + \text{T}_{\text{JAN}})}{2}\right) + \frac{365}{2\pi}\left(40 - \frac{(\text{T}_{\text{JUL}} + \text{T}_{\text{JAN}})}{2}\right) \frac{\text{T}_{\text{JUL}} - \text{T}_{\text{JAN}}}{\text{T}_{\text{JUL}} - \text{T}_{\text{JAN}}}$$

$\text{DEGD}_{\text{MIN}}$  = minimum range of degree days for a species

$\text{DEGD}_{\text{MAX}}$  = maximum range of degree days for a species

$\text{T}_{\text{JUN}}$  = average temperature for month of June

$\text{T}_{\text{JAN}}$  = average temperature for month of January

Stand Biomass Modifier:

$$S(\text{BAR}) = 1 - \frac{\text{BAR}}{\text{SOILQ}}$$

where

$\text{BAR}$  = total basal area on plot

$\text{SOILQ}$  = maximum basal area of a stand of trees  
under optimal growing conditions  
( $\text{BA} = 140$  was used for ELF sites)

Available Light Modifier:

$$R(AL) = 1 - e^{-4.64(AL-.05)}, \text{ for shade tolerant trees}$$

or

$$R(AL) = 2.24(1 - e^{-1.136(AL-.08)}), \text{ for shade intolerant trees}$$

where

$$AL = PHI e^{-k(SLA)}$$

$$PHI = 1$$

$$K = \frac{1}{6000} \text{ for } 10 \times 10 \text{ plots}$$

$$SLA = \text{shading leaf area for all trees above given tree}$$

Coefficients:

#### JABOWA Model

Species	G	$D_{MAX}/H_{MAX}$	$b_2$	$b_3$	$DEGD_{MIN}$	$DEGD_{MAX}$
RM	240	152.5/3660	46.3	.152	2000	12400
PB	140	46.0/1830	76.3	.800	1100	3700

#### FORET Model

Species	G	$D_{MAX}/H_{MAX}$	$b_2$	$b_3$	$DEGD_{MIN}$	$DEGD_{MAX}$
NRO	61.8	244.0/4877	28.70	.079	731	8499
RM	239.5	152.5/3660	52.58	.173	1810	13395

## APPENDIX F

Performance of Existing Diameter Growth Models in  
Predicting Diameter Growth on ELF Study Sites

APPENDIX F. DETERMINING DETERMINANT FACTORS

## U.S.D.A. Model

	Average			Standard Deviation			PVE
	Observed	Predicted	Residual	Observed	Predicted	Residual	
Control							
ALL	.194	.405	-.211	.134	.036	.123	- 2.35
NRO	.202	.408	-.205	.132	.016	.175	- 2.33
PB	.077	.363	-.285	.080	.056	.072	-12.67
BTA	.302	.425	-.124	.117	.024	.112	- 1.03
RM	.204	.437	-.233	.056	.034	.167	-17.45
QA	.215	.426	-.211	.138	.049	.148	- 2.51
Antenna							
ALL	.182	.455	-.274	.143	.032	1.42	- 3.67
NRO	.244	.437	-.193	.155	.019	.155	- 1.57
PB	.194	.445	-.250	.099	.086	.077	- 5.98
BTA	.366	.483	-.117	.171	.053	.189	- .69
RM	.138	.459	-.321	.107	.021	.102	- 8.86

NRO = Northern Red Oak

PB = Paper Birch

BTA = Big Tooth Aspen

RM = Red Maple

QA = Quaking Aspen

## Optimum JABOWA Model

	Average			Standard Deviation			PVE
	Observed	Predicted	Residual	Observed	Predicted	Residual	
Control							
ALL	.112	.723	-.611	.093	.480	.437	- 64.12
PB	.077	.433	-.356	.079	.088	.145	- 22.32
RM	.204	1.497	-1.293	.056	.032	.064	-526.96
Antenna							
ALL	.141	1.476	-1.334	.108	.267	.299	-160.38
PB	.194	.414	-.220	.099	.092	.147	- 6.12
RM	.138	1.542	1.404	-.107	.039	.110	-171.15

## Modified JABOWA Model

	Average			Standard Deviation			PVE
	Observed	Predicted	Residual	Observed	Predicted	Residual	
Control							
ALL	.112	.252	-.140	.093	.116	.192	- 5.53
PB	.077	.309	-.232	.079	.062	.137	-10.47
RM	.204	.099	.104	.056	.002	.056	- 3.43
Antenna							
ALL	.141	.077	.065	.108	.029	.108	-.38
PB	.194	.186	.008	.099	.042	.114	-.34
RM	.138	.070	.068	.107	.002	.107	-.40



## Optimum FORET Model

	Average			Standard Deviations			PVE
	Observed	Predicted	Residual	Observed	Predicted	Residual	
Control							
ALL	.202	.689	- .487	.177	.193	.217	- 16.50
NRO	.202	.633	- .431	.131	.029	.110	- 10.46
RM	.204	1.339	-1.135	.056	.027	.062	-406.33
Antenna							
ALL	.165	1.91	-1.026	.130	.324	.388	- 70.42
NRO	.243	.645	- .402	.154	.038	.151	- 6.76
RM	.138	1.381	-1.244	.107	.033	.108	-133.98

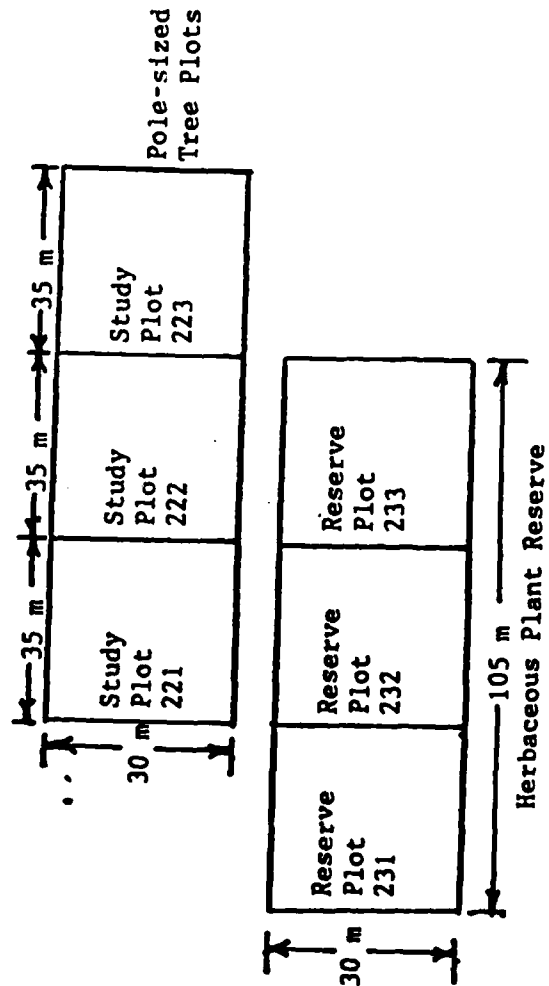
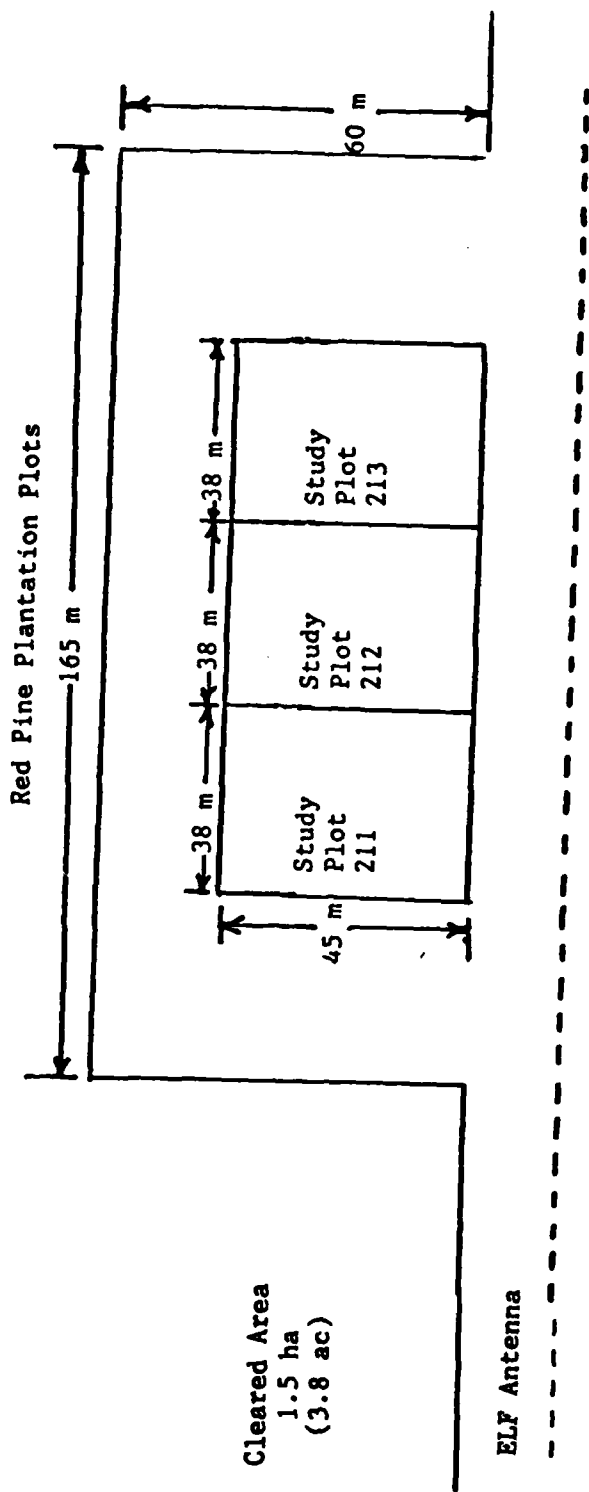
## Modified FORET Model

	Average			Standard Deviation			PVE
	Observed	Predicted	Residual	Observed	Predicted	Residual	
Control							
ALL	.202	.159	.044	.177	.016	.123	- .048
NRO	.202	.163	.039	.131	.007	.126	- .004
RM	.204	.109	.095	.056	.002	.056	- 2.83
Antenna							
ALL	.165	.119	.047	.130	.040	.121	.005
NRO	.243	.186	.057	.154	.011	.153	- .115
RM	.138	.095	.043	.107	.002	.107	- .157

APPENDIX G

Maps of the Three Study Sites of the  
Trees and Herbaceous Plants Study

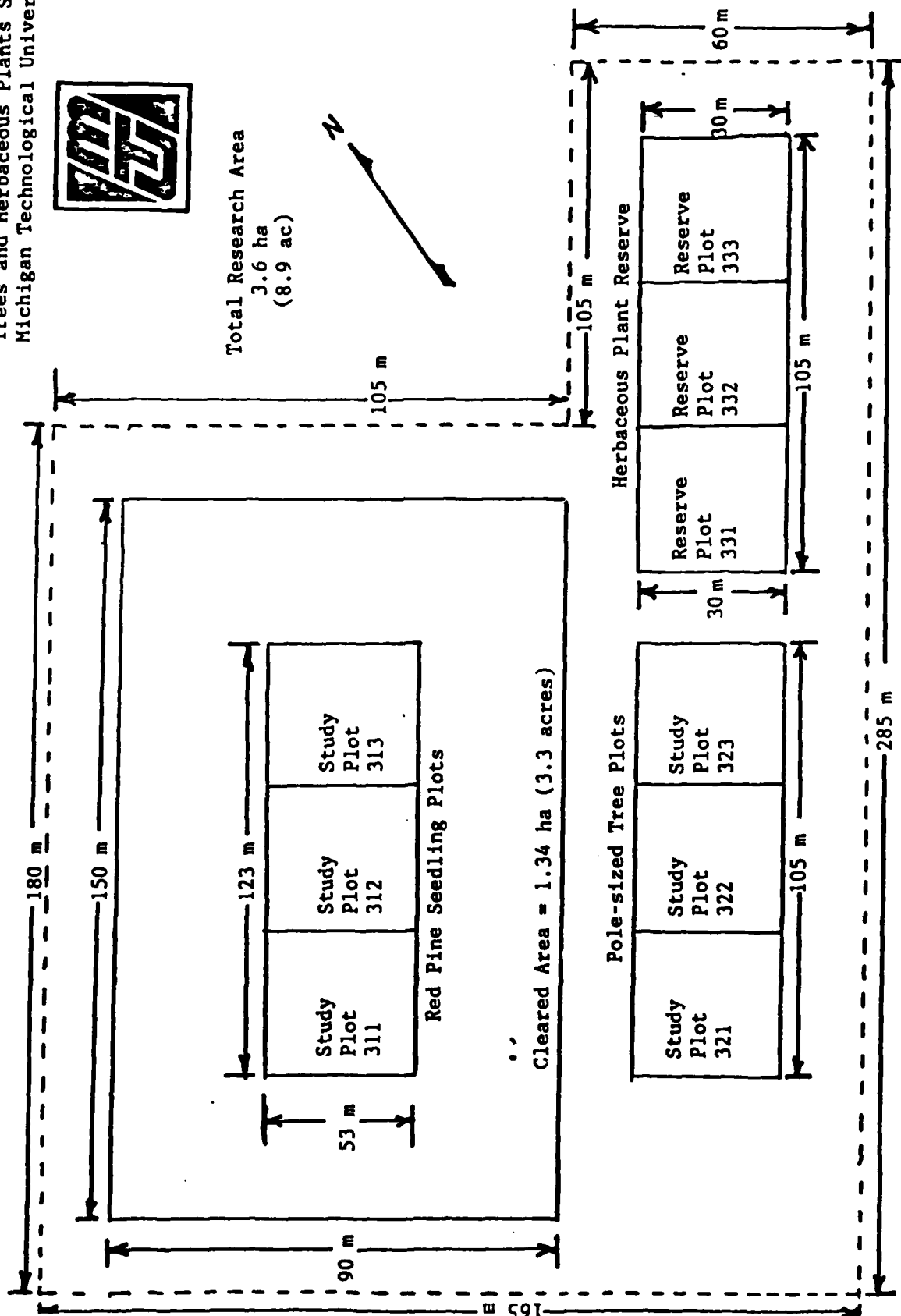
# Antenna Test Plots



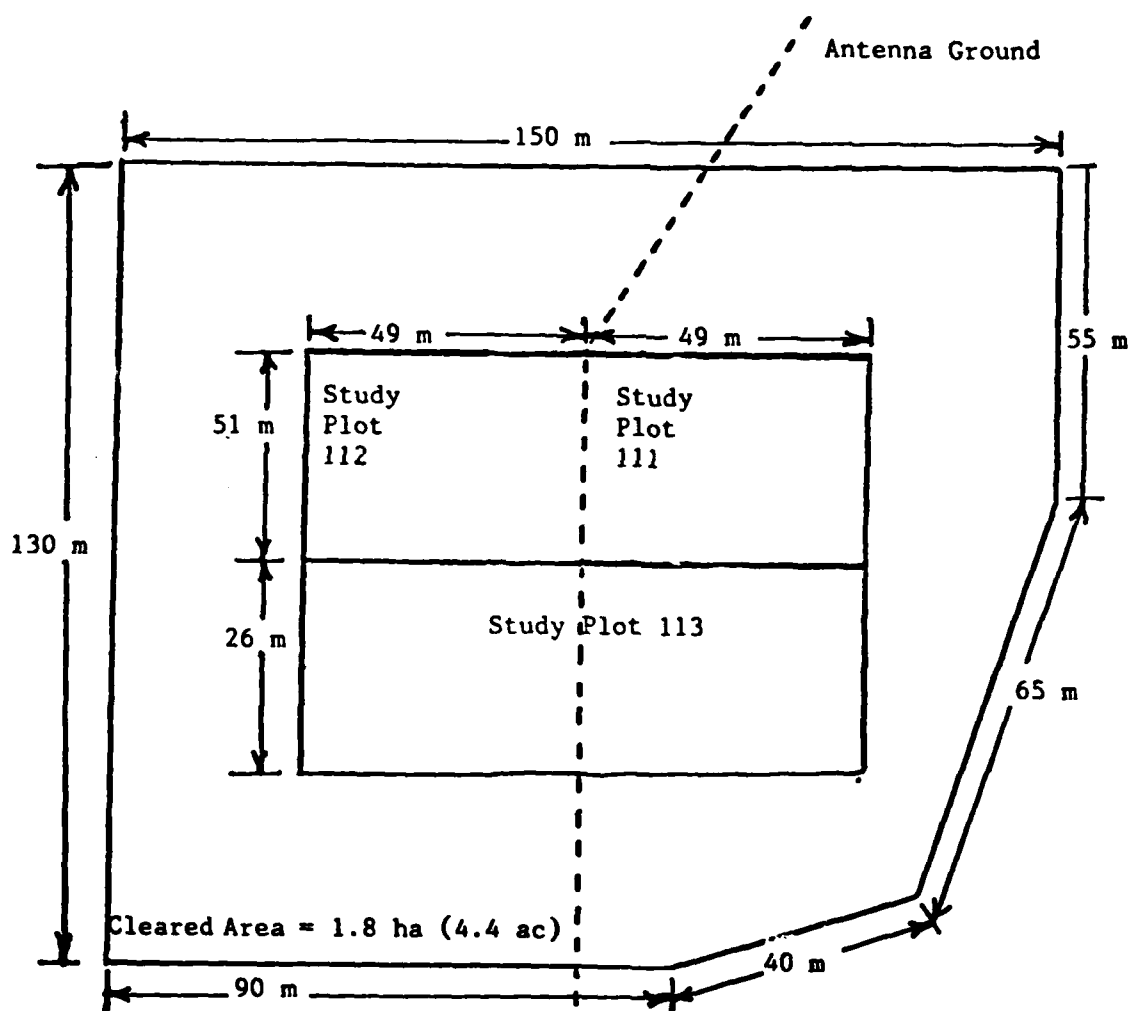
ELF Ecological Monitoring Program  
Trees and Herbaceous Plants Study  
Michigan Technological University



Total Research Area  
3.6 ha  
(8.9 ac)



## Ground Terminal Plantation Plots



ELF Ecological Monitoring Program  
Trees and Herbaceous Plants Study  
Michigan Technological University



APPENDIX H

Summary of Seedling Variables Collected  
for Each Sampling Date by Site

<u>Date</u>	<u>Site</u>	<u>Basal Diam. (cm)</u>	<u>Candle Length (cm)</u>	<u>Height (cm)</u>	<u>PMS (Bars)</u>	<u>Shoot Weight (g)</u>	<u>Root Weight (g)</u>	<u># of Myc. Root Tips</u>	<u>Myc/Gram Roots</u>	<u>Shoot Root Ratio (Weight Basis)</u>
May 21	GND	0.84	1.7		23.2	5.76	2.29	2583	1055	2.58
	ANT	0.80	2.6		21.7	7.00	2.54	3617	1312	2.90
	CTL	1.00	3.4		11.0	7.84	2.75	2668	1032	2.88
June 18	GND	0.65	5.4	22.0	5.0	8.63	3.20	2543	1294	2.87
	ANT	0.64	7.1	21.3	5.0	9.09	3.15	2747	888	3.02
	CTL	0.70	7.3	26.7	6.4	10.28	3.34	2602	852	3.16
July 16	GND	0.72	6.7	26.7	6.2	14.07	3.66	2768	746	4.06
	ANT	0.64	8.5	24.1	6.5	10.93	2.08	2864	1236	5.82
	CTL	0.76	13.9	31.3	6.8	20.48	4.54	4905	1134	4.73
Aug. 21	GND	0.72	7.2	23.6	5.9	12.98	3.10	2929	1101	4.23
	ANT	0.70	8.4	23.1	5.7	14.13	2.68	2471	967	5.33
	CTL	0.74	8.3	27.6	6.4	19.67	3.87	2723	642	5.14
Sept. 25	GND	0.68	6.6	22.8	19.4	16.21	4.58	5257	1289	3.55
	ANT	0.84	8.0	22.9	21.5	17.96	5.06	4070	942	3.50
	CTL	0.82	11.1	29.3	25.5	19.16	5.54	5464	996	3.47
Oct. 23	GND	0.80	7.3	24.4		18.17	5.33	3924	697	3.48
	ANT	0.82	8.8	27.7		21.17	5.45	4643	839	3.98
	CTL	0.89	9.3	27.6		22.35	6.69	8793	1289	3.50

ELF COMMUNICATIONS SYSTEM ENVIRONMENTAL MONITORING PROGRAM:  
LITTER DECOMPOSITION AND MICROFLORA  
The Michigan Study Site

ANNUAL REPORT, 1985

SUBCONTRACT NUMBER: E06549-84-C-002

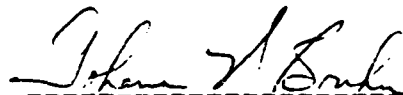
MICHIGAN TECHNOLOGICAL UNIVERSITY  
HOUGHTON, MICHIGAN



ELF COMMUNICATIONS SYSTEM ENVIRONMENTAL MONITORING PROGRAM:  
LITTER DECOMPOSITION AND MICROFLORA  
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ANNUAL REPORT, 1985  
SUBCONTRACT NUMBER: E06549-84-C-002

PROJECT MANAGER:

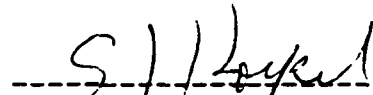


Johann N. Bruhn  
Research Scientist

INVESTIGATORS:

Susan Bagley  
Johann Bruhn

RELEASING AUTHORITY:



Edward J. Koepel  
Vice President of Operations and Finance

MICHIGAN TECHNOLOGICAL UNIVERSITY  
HOUGHTON, MICHIGAN

## TABLE OF CONTENTS

SUMMARY -----	1
INTRODUCTION -----	5
ELEMENT 1. LITTER DECOMPOSITION AND NUTRIENT FLUX -----	7
Introduction -----	7
Methods -----	8
Description of Progress -----	12
ELEMENT 2. RHIZOPLANE AND RHIZOPLANE ACTINOMYCETES -----	119
Introduction -----	119
Methods -----	120
Description of Progress -----	123
LITERATURE CITED -----	133
Appendix A. Single Exponential Decomposition Models for 1984 Data -----	137

## SUMMARY

### Litter Decomposition and Nutrient Flux

The 1985 field season represents 1) the second full year of experience with red pine on the ELF antenna and ground sites, 2) the first full year of study at the ELF control site, 3) the first full year of experience with northern red oak and red maple in addition to red pine, and 4) the first field season for which relatively complete weather data are available. Final selection of a control site was made too late to be included in the 1983-84 (early December, 1983, to early December, 1984) litter decomposition/ nutrient flux experiment.

The 1984-85 litter decomposition/ nutrient flux experiment was broadened beyond the 1983-84 experiment to include monthly samples from early May to early December of northern red oak and red maple as well as red pine. The 1984-85 study included all three plantations and the two pole stands. Single exponential models were fitted to the data representing each study species at each plantation and pole-stand. Results of analysis to date compare well with those for 1983-84. Raw mass loss data have been analyzed by analysis of variance for differences between species, study locations, and sampling dates. The potential value of using transformed data in some analyses is being explored. Similar analyses comparing pine data from the 1983-84 and 1984-85 experiments at the ground and antenna sites are being developed. To date, it can be said that maple apparently decomposed faster than either oak or pine, and that individual bagged oak leaves decomposed faster than did individual bagged pine fascicles ( $\alpha = .05$ ). The only significant difference ( $\alpha = .05$ ) in decomposition progress by species between study locations was that individual bagged maple leaves decomposed least rapidly in the Antenna and Control site pole-stands. Compositing mass loss data by species for all study locations, it is apparent that decomposition progresses significantly ( $\alpha = .05$ ) during most months of the growing season until September (for maple) or October (for pine and oak).

Correlation analyses between mass loss and parameters of

air temperature and precipitation pointed out the importance of these weather variables in the explanation or (ultimately) prediction of mass loss progress during a month or between years (Jansson and Berg 1985, Smith 1982). The dependence of decomposition rate on both current and previous weather also underscores the artificiality of deriving single exponential models to fit our field data. Application of analysis of variance and covariance techniques, and possibly linear programming, seem to offer more meaningful potential for our studies.

Data on the influence of litter fragmentation on apparent litter decomposition rates was collected and will be analyzed as soon as time and budget permit. Based on our experience during the 1984-85 study, it seems unlikely that fragmentation data can be integrated meaningfully into our estimation of mass loss.

Data from the 1983-84 study showed that the patterns of overall and nutrient mass loss between study locations were very similar. No significant differences were detected for overall mass loss or for change in total nitrogen content between locations for given dates. However, litter placed in the Antenna site pole-stand lost phosphorus, potassium, calcium and magnesium more slowly than did litter placed in the plantations, or even recovered nutrient mass (especially potassium) late in the season. All samples collected as part of the 1984-85 study have been ground and are currently being analyzed for their dry weight content of N, P, K, Ca, and Mg. In this report, we present the first half of the N and P data (early May through early August) for all three species. Bulk pine sample nitrogen content was the same through July of both 1984 and 1985, at the Ground and Antenna sites. Bulk pine samples from the 1984-85 study appear to have maintained their initial P content more effectively than did comparable samples from the 1983-84 study. Statistical analysis of nutrient data will proceed as soon as results of chemical analysis become available.

Emphasis in 1986 will focus on adding another year's pre-operational (with respect to ELF) experience with all three test species. An attempt will be made to model the influences of pre-

cipitation and air temperature on pine, oak and maple foliar litter decomposition in the field.

#### Rhizoplane Streptomycetes

Rhizoplane streptomycete work continues to focus on the three red pine plantations. Study of streptomycetes associated with red pine seedling mycorrhizae commenced with planting in June of 1984. As in 1984, the primary mycorrhizal root type detected during 1985 from all plantation sites was mycorrhizal root type 3. Using analysis of variance techniques, the levels of streptomycetes associated with washed type 3 roots were found to be significantly lower at the control site as compared to the antenna and ground sites. Levels of streptomycetes detected in October were significantly lower at all sites than were the levels detected from May, July, and August. There was no significant difference between sites in terms of the number of types of streptomycetes present with the washed type 3 mycorrhizal roots. The lowest number of types (at all sites) was detected in October, and the highest number detected was in May. The difference in numbers of types detected between months was significant only for the May vs. October contrast. Streptomycetes were isolated from type 3 mycorrhizal fine root tip enrichments from all sites at all sampling times. As expected, fewer types were recovered from the fine root tips as compared to the washed roots. One streptomycete morphological type predominated in all washed root samples (regardless of site and date); this same type was also commonly isolated from the fine root tip enrichments.

Comparisons between mycorrhizal type 3 washed root streptomycete levels and types from 1985 to similar data obtained during 1984 indicate that the 1985 data all fall within the range of values reported during 1984. The 1985 data are considered to be more accurate as more replicates were tested for each site and date. More detailed characterizations of the streptomycete morphological types identified during 1985 were conducted in order to compare the 1985 and 1984 streptomycete types. The predominant streptomycete type associated with these red pine seed-

lings' roots at the time of lifting at the Toumey Nursery, and which could be detected in mycorrhizal root samples collected from the ELF plantations at least through August, 1984, can no longer be detected in association with the mycorrhizal roots, indicating that selection processes have affected the streptomy-cete populations in the field. Although many streptomycete types were detected from the various sites throughout the 1985 sampling season, one streptomycete type dominated at all sites on all dates from both the washed root and root tip enrichment samples.

Emphasis in 1986 in the rhizoplane streptomycete element will be placed on the washed mycorrhizal root studies, which can provide quantitative data for use in monitoring possible ELF field effects; the number of samples per plot at each sampling period will be doubled in order to increase the power of the statistical analyses. Improvements have been designed to the root tip enrichment technique which should improve recovery of streptomycetes from enrichments.

Both work elements of this project make use of the ambient weather monitoring system operated and maintained by the Herbaceous Plant Cover and Tree Studies project (Element 2), and both work elements remain closely tied to the mycorrhiza (Elements 6 and 7) and litter production (Element 8) study elements of that project. Litter decomposition is shown to be significantly correlated with precipitation and air temperature, as anticipated. Monthly mass losses appear to be at least as sensitive to the previous month's weather as to that of the current month.

## INTRODUCTION

The litter decomposition subsystem of any forest ecosystem serves to 1) pool the nutrients relinquished by primary producers, 2) transform the essential nutrients remaining in litter or trapped by it into forms available for root uptake, and 3) release these nutrients in a regulated fashion for re-use by the autotrophs. The energy provided by litter decomposition also fuels heterotrophic dinitrogen fixation and the capture of nutrients washed from the atmosphere or leached from living plants. Due to the large quantities of potentially available plant nutrients found in the litter component of forest biomass, knowledge of key decomposition processes and their rates is essential to conceptualization of ecosystem dynamics. Organic matter decomposition is primarily accomplished by heterotrophic microorganisms whose activities are regulated by the environment. Recognizing the delicate balance of ecosystem functioning, it is apparent that environmental factors which disrupt decomposition processes detract from the optimum flow of nutrients to vegetation. As one such environmental factor, ELF electromagnetic fields merit investigation for possible effects on the litter decomposition subsystem.

Litter decomposition is a complex process involving a variety of organisms engaged in the degradation of a wide range of organic compounds. The primary agents of organic matter decomposition are the fungi and bacteria. Within these broad groups, a relatively small cadre are responsible for degradation of complex structural materials such as cellulose and lignin. Among the fungi, cellulose and lignin degradation are accomplished by members of the Basidiomycetes and Ascomycetes. Of the bacteria, members of the Actinomycetes have been found to degrade cellulose and lignin/lignocellulose in both coniferous and deciduous litter systems. Streptomyces have also been implicated in the calcium and phosphorus nutrition of conifer mycorrhizae and could influence mycorrhizosphere microbial composition through production of antibiotics, growth factors, etc.

The broad objectives of this study are: 1) to characterize a) the rates of foliar organic matter decomposition and nutrient cycling and b) populations of mycorrhiza-associated streptomycetes on selected sites within the ELF antenna area prior to operation of the antenna, and 2) to use these baseline data to evaluate possible ELF field effects on these sensitive processes and populations. Although the two work elements represented in this project (reflected in 1a and 2b above) may appear disjointed, the relevance of each element is readily apparent when viewed in conjunction with the Herbaceous Plant Cover and Tree Species project as an integrated whole.



Element 1: Litter Decomposition and Nutrient Flux

Introduction

Total litter mass loss has traditionally been used as a measure of fully integrated litter decomposition. It has been shown, however, that both the accuracy and precision of mass loss as a sensitive index of organic matter deterioration declines with time beyond approximately one year, depending on the ecosystem, while nutrient flux provides continuously meaningful ecological information. Within this framework, we are finding that mass loss characterization on the basis of individual leaves provides additional biologically meaningful information about the decomposition process and the rates at which it naturally proceeds for different litter species beyond that provided by study of mass loss for bulk samples. Bulk sample estimates of mass loss rates actually represent running averages of the decomposition rates operating in the individual leaves comprising the bulk sample. These average rates are nevertheless essential for conversion of nutrient concentrations determined for bulk litter samples from per cent values to masses for calculation of nutrient flux.

Microfloral population shifts have been shown to influence the rate of total litter decomposition (Mitchell and Millar 1978). Conversely, total litter mass loss and nutrient flux are useful measures of the impact of environmental perturbations on the integrated activities of the litter biota. ELF fields represent one possible cause of perturbations.

Litter decomposition/ nutrient flux studies greatly extend the usefulness of litter productivity data collected in the course of forest vegetation studies. Knowledge of litter biomass production and nutrient content likewise serve as the basis for decomposition study. Further, the study methods employed in these studies integrate the activities of the microflora with all but the largest arthropods and earthworms, extending the value of all population data. Enchytraeid worms, arachnids, ants, and representatives of various beetle families were commonly found in

samples retrieved during the second half of the growing season. In a few cases, individuals apparently entered sample envelopes as immatures, only to be found there later as adults too large to have entered the envelopes as such.

Since the 1984 Annual Report was written, an entire year's experience with red pine, northern red oak, and red maple foliar litter decomposition and nutrient flux has been gained on the Antenna, Ground, and Control sites. Experience gained supports the contention that total and nutrient mass loss over time from freshly fallen foliar litter can be characterized with sufficient precision to detect environmental perturbation.

#### Methods

Litter decomposition is being quantified as percent change over time in total mass and nutrient (N, P, K, Ca, and Mg) masses. Analysis of litter nutrient content is being conducted by the Soils Analysis Laboratory, Department of Forestry, Michigan Technological University.

1984-85 Study.--Fresh-fallen red pine litter was again collected on polyethylene tarps (provided with drainage) spread in the LaCroix red pine plantation near Houghton, due to 1) its proximity to MTU, and 2) its relative remoteness from interfering electromagnetic fields. Fresh-fallen red maple litter was collected along the Covered Drive, seven miles from Houghton, for the same reasons. Northern red oak litter was similarly collected along the northeast edge of the Control site plantation plot 313. A single parent litter collection, from a single location, for each species avoids the effects of 1) differences which might be present in substrate quality between different litter sources, and 2) differences in substrate quality between litter sources which might develop as a result of ELF field effects. Accommodation of the potential for either type of effect would unnecessarily complicate the experimental design and would greatly increase the number of samples required in order to maintain statistical power. We feel that the additional expense attached to expanding the experimental design to include separate

litter collections from each site is not warranted.

Fresh:dry mass ratios and initial nutrient content were determined for 10 random samples taken from each of the pine, oak, and maple litter parent collections. All mass loss data (total as well as nutrient masses) are based on 30°C dry masses. Random subsamples from the parent litter collection were placed in replicate nylon mesh envelopes (3 mm nylon mesh). Bulk pine sample envelopes measure 22 cm x 28 cm, each containing 10 g (air dry weight) of the parent collection. Tethered pine fascicle envelopes measure 22 cm x 14 cm. Each tethered foliage envelope contained 10 perfect preweighed fascicles or leaves tethered along an approximately 30 cm long section of 6 lb test nylon monofilament line. Bulk maple and bulk oak sample envelopes measure 44 cm x 28 cm, each containing 12 g (air dry weight) of the parent collection. Tethered maple and oak leaf envelopes measured 22 cm x 28 cm. All envelopes are constructed to lay flat on the ground. Tethered, unbagged samples for pine and oak were constructed in the same manner as bagged samples, and were simply staked to the ground at one end of their nylon tether.

Four bulk litter envelopes and two tethered foliage envelopes were disbursed at five random locations on each of the 15 study plots. Total mass loss was studied by a tethered fascicle/leaf method as well as via bulk litter samples, while nutrient flux was determined solely for the bulk litter samples. Fascicles offer the opportunity to study litter decomposition without the errors associated with litter losses from and inputs to envelopes over the course of an experiment. Each tethered fascicle or leaf was perfectly intact at the time of disbursal, so that fragmentation associated with decomposition can be quantified. Fascicles broken during the course of an experiment can be discarded prior to analysis. Finally, in order to compare bagged with unbagged specimens, tethered, unbagged individual pine fascicles and oak leaves were also placed in the field on one plot each of the control site plantation and pole-stand.

Each month, from 1 May through 1 December, 1985, two bulk sample envelopes and one tethered foliage envelope for each

species were retrieved from each of the 15 plots (3 plots each in the Ground, Antenna and Control site plantations, and in the Antenna and Control site pole-stands). Also, one set each of tethered unbagged pine fascicles and oak leaves was retrieved from plantation plot 311 and pole-stand plot 321 at the Control site. As a result, decomposition estimates will be based on 6 bulk samples and as many as 30 fascicles or leaves (depending on fragmentation) for each species on each site and date.

Sample sizes were based on the results of the 1982-83 pilot study with red pine and paper birch at Martels Lake, and on the results of the 1983-84 study with red pine on the Antenna and Ground sites. Snow cover at the study sites dictated early May to be the earliest possible recovery date, as samples are frozen to the ground until snowmelt is complete. Sufficient samples were recovered each month to permit both 1) analysis of differences in total and nutrient masses between species, dates, and sites by analysis of variance with multiple range comparisons made via Duncan's new multiple range test, and 2) analysis of the single exponential decomposition model rate constants ( $k$ ) derived by fitting the year's total mass loss data for each species on each plantation and pole-stand to an equation of the form  $Y = e^{-kt}$  (Wieder and Lang 1982). Single exponential models were derived using the program BMDPAR, designed for derivative-free nonlinear regression. Rate constants were compared statistically by calculation of confidence intervals based on the asymptotic standard deviations derived by the software. In all statistical analyses performed, acceptance or rejection of the null hypothesis was based on  $\alpha = .05$ , regardless of the test criterion involved, although differences which are significant with  $P \leq .05$  are reported as such.

Weather data collected by the Herbaceous Plant Cover and Tree Studies project is proving to be very useful by helping to explain monthly variations in decomposition rates at the study sites. No doubt this data will be very helpful in explaining differences in decomposition rates between years as well. Ambient monitoring variables which will receive special attention include

air temperature and precipitation. Preliminary correlation analyses have been conducted between various parameters of these two weather variables and total mass loss for each litter species on a monthly basis. Lack of weather data for most of 1984 prevented evaluation of the influence of environmental variables on decomposition during 1984. At present, we are evaluating two different methods of incorporating precipitation and air temperature data into our experimental design: 1) analysis of covariance to factor routine environmental variables out of comparisons of decomposition progress between sites, dates and years, and 2) linear modelling, using weather data to help explain monthly changes in the rates at which decomposition proceeds.

In order to further compare the bulk litter and tethered fascicle methods of quantifying decomposition, moisture content at the time of retrieval was determined for most samples. Each retrieved sample was placed in an air-tight plastic freezer-storage bag from which as much air as possible was then removed. When tethered samples were too fragile to evacuate for fear of fragmentation, moisture content could not be determined. This generally only occurred on the plantation plots during dry weather. Fresh "wet" weights were recorded in the laboratory prior to drying to a constant mass at 30°C, which was also recorded. Moisture content at the time of retrieval was then calculated as wet weight minus dry weight divided by dry weight. The influence of moisture on decomposition via the bulk sample versus the tethered fascicle method will be evaluated as time and budget permit.

Fragmentation was studied by determining the per cent of leaf surface area lost over time by individual oak and maple leaves. Photocopy replicas of the individual tethered leaves placed in the field will be used for comparison of initial and final leaf dimensions. Leaf surface area will be determined using a photoelectric cell leaf area meter. It may be possible to weight total mass loss data for oak and maple by a factor which accounts for fragmentation. An experiment was established to estimate the rate of decomposition of litter fragments which

filter into the fermentation layer of the forest floor. Such fragments should decompose faster than the litter remaining at the forest floor surface (Witkamp and Olson 1963). Characterization of these accelerated rates would enhance the potential to accurately model first year decomposition processes at the study sites. Analysis of these data will proceed as time and budget permit.

1985-86 Study.-- Fresh-fallen red pine, northern red oak, and red maple foliar litter was collected as described for the 1984-85 study. The same basic experimental design established for the 1984-85 study is being followed for the 1985-86 study. Because we were unable to collect two months samples in 1985, intended for retrieval in January and April, these samples will be retrieved in 1986. If their condition permits, we will retrieve one set in May and the other in November.

#### Description of Progress

1984-85 Study.-- Tables 1 through 6 present changes in total mass for bulk samples and individual fascicle/leaf samples of all three litter species which took place during their first year of decomposition at all five study locations. The raw mass loss data (in the form of "X", the proportion of original sample mass remaining) have been analyzed using the SPSS subprograms "ANOVA", for two way analysis of variance, and "ONEWAY", for one way analysis of variance with multiple comparison tests and tests for homogeneity of variances. Figures 1 through 15 present the bulk sample mass loss data for all three species graphically. Figures 16 through 30 present the tethered bagged sample mass loss data for all three species, and Figures 31 and 32 present the tethered unbagged mass loss data for pine and oak.

A complete report on the results of analysis of variance will be provided as soon as study of the effects of data transformation on homogeneity of variances are complete. The following insights are available at this time. Mass loss data for the 1 November, 1985, sampling show that bulk pine and oak litter samples retrieved on that date had lost significantly less mass

Table 1. Mean proportion<sup>a</sup> of initial overall mass (30°C) remaining at different times in 1985, for bulk red pine foliar litter samples disbursed in early December, 1984.

Sample Retrieval Date	Ground Site Plantation	Antenna Site	
		Plantation	Pole-stand
30 April	0.90 (0.01) <sup>b</sup>	0.92 (0.01)	0.89 (0.00)
2 June	0.85 (0.01)	0.88 (0.01)	0.83 (0.01)
3 July	0.83 (0.01)	0.86 (0.01)	0.84 (0.02)
31 July	0.82 (0.02)	0.84 (0.02)	0.84 (0.04)
27 August	0.76 (0.02)	0.78 (0.03)	0.77 (0.01)
31 October	0.71 (0.01)	0.72 (0.01)	0.71 (0.01)
2 November	0.70 (0.05)	0.72 (0.02)	0.71 (0.02)
1 December			0.72 (0.02)

Table 1. (cont)

Sample Retrieval Date	Control Site	
	Plantation	Pole-stand
30 April	0.89 (0.01)	0.89 (0.01)
2 June	0.86 (0.01)	0.83 (0.00)
3 July	0.83 (0.01)	0.83 (0.01)
31 July	0.80 (0.01)	0.81 (0.02)
27 August	0.80 (0.04)	0.77 (0.01)
31 October	0.73 (0.03)	0.71 (0.01)
2 November	0.71 (0.02)	0.70 (0.02)
1 December		0.70 (0.01)

<sup>a</sup>/ Proportion ( $X=W_1/W_0$ ), where  $W_0$  and  $W_1$  represent the 30°C dry weights of samples initially and at time 1, respectively. Dry weight at time 0 was estimated from fresh to dry weight (30°C) ratios determined for separate random subsamples taken at the time of litter sample preparation. These samples were also used to determine initial nutrient content.

<sup>b</sup>/ standard deviation

Table 2. Mean proportion<sup>a</sup> of initial overall mass (30°C) remaining at different times in 1985, for tethered red pine foliar litter samples disburied in early December, 1984.

Sample Retrieval Date	Ground Site Plantation	Antenna Site	
		Plantation	Pole-stand
30 April	0.93 (0.01) <sup>b</sup>	0.95 (0.02)	0.91 (0.01)
2 June	0.90 (0.02)	0.90 (0.01)	0.88 (0.01)
3 July	0.88 (0.03)	0.88 (0.02)	0.88 (0.03)
31 July	0.85 (0.03)	0.88 (0.04)	0.86 (0.03)
27 August	0.81 (0.02)	0.81 (0.03)	0.81 (0.02)
31 October	0.75 (0.02)	0.76 (0.03)	0.75 (0.03)
2 November	0.72 (0.06)	0.74 (0.04)	0.72 (0.03)
1 December			0.76 (0.03)

Table 2. (cont)

Sample Retrieval Date	Control Site			
	Plantation		Pole-stand	
	Bagged	Unbagged	Bagged	Unbagged
30 April	0.93 (0.01)	0.96 (0.01)	0.89 (0.03)	0.92 (0.01)
2 June	0.89 (0.03)	0.93 (0.02)	0.86 (0.02)	0.89 (0.01)
3 July	0.87 (0.03)	0.89 (0.01)	0.82 (0.03)	0.90 (0.01)
31 July	0.82 (0.03)	0.84 (0.06)	0.82 (0.03)	0.85 (0.04)
27 August	0.84 (0.07)	0.81 (0.11)	0.78 (0.03)	0.84 (0.02)
31 October	0.74 (0.03)	0.76 (0.04)	0.71 (0.03)	0.74 (0.02)
2 November	0.73 (0.02)	0.73 (0.01)	0.70 (0.03)	0.72 (0.02)
1 December			0.70 (0.04)	

a/ Proportion ( $X=W_1/W_0$ ), where  $W_0$  and  $W_1$  represent the 30°C dry weights of samples initially and at time 1, respectively. Dry weight at time 0 was estimated from fresh to dry weight (30°C) ratios determined for separate random subsamples taken at the time of litter sample preparation.

b/ standard deviation



Table 3. Mean proportions<sup>a</sup> of initial overall mass (30°C) remaining at different times in 1985, for bulk northern red oak foliar litter samples disbursed in early December, 1984.

Sample Retrieval Date	Ground Site Plantation	Antenna Site	
		Plantation	Pole-stand
30 April	0.92 (0.02) <sup>b</sup>	0.92 (0.03)	0.92 (0.01)
2 June	0.88 (0.01)	0.87 (0.03)	0.88 (0.01)
3 July	0.85 (0.01)	0.86 (0.02)	0.89 (0.02)
31 July	0.81 (0.02)	0.83 (0.02)	0.88 (0.03)
27 August	0.75 (0.03)	0.78 (0.02)	0.81 (0.02)
31 October	0.69 (0.03)	0.70 (0.04)	0.73 (0.04)
2 November	0.68 (0.04)	0.74 (0.07)	0.78 (0.09)
1 December			0.65 (0.03)

Table 3. (cont)

Sample Retrieval Date	Control Site	
	Plantation	Pole-stand
30 April	0.95 (0.01)	0.93 (0.01)
2 June	0.90 (0.02)	0.90 (0.01)
3 July	0.85 (0.02)	0.87 (0.01)
31 July	0.84 (0.02)	0.87 (0.04)
27 August	0.79 (0.03)	0.79 (0.02)
31 October	0.75 (0.07)	0.70 (0.03)
2 November	0.69 (0.11)	0.68 (0.03)
1 December		0.62 (0.02)

<sup>a</sup>/ Proportion ( $X=W_1/W_0$ ), where  $W_0$  and  $W_1$  represent the 30°C dry weights of samples initially and at time 1, respectively. Dry weight at time 0 was estimated from fresh to dry weight (30°C) ratios determined for separate random subsamples taken at the time of litter sample preparation. These samples were also used to determine initial nutrient content.

<sup>b</sup>/ standard deviation

Table 4. Mean proportions<sup>a</sup> of initial overall mass (30°C) remaining at different times in 1985, for tethered northern red oak foliar litter samples disbursed in early December, 1984.

Sample Retrieval Date	Ground Site Plantation	Antenna Site	
		Plantation	Pole-stand
30 April	0.92 (0.03) <sup>b</sup>	0.93 (0.03)	0.91 (0.03)
2 June	0.86 (0.06)	0.87 (0.05)	0.86 (0.04)
3 July	0.80 (0.07)	0.84 (0.06)	0.89 (0.07)
31 July	0.77 (0.09)	0.81 (0.08)	0.85 (0.04)
27 August	0.73 (0.10)	0.78 (0.11)	0.81 (0.06)
31 October	0.65 (0.10)	0.65 (0.14)	0.74 (0.10)
2 November	0.60 (0.11)	0.63 (0.17)	0.65 (0.06)
1 December			0.69 (0.08)

Table 4. (cont)

Sample Retrieval Date	Control Site			
	Plantation		Pole-stand	
	Bagged	Unbagged	Bagged	Unbagged
30 April	0.95 (0.03)	0.96 (0.02)	0.93 (0.03)	0.92 (0.03)
2 June	0.88 (0.06)	0.86 (0.04)	0.88 (0.04)	0.90 (0.04)
3 July	0.84 (0.06)	0.85 (0.07)	0.87 (0.05)	0.89 (0.02)
31 July	0.80 (0.08)	0.76 (0.09)	0.84 (0.06)	0.86 (0.03)
27 August	0.75 (0.08)	0.74 (0.07)	0.83 (0.05)	0.79 (0.07)
31 October	0.67 (0.11)	0.71 (0.08)	0.67 (0.09)	0.61 (0.11)
2 November	0.65 (0.11)	0.69 (0.10)	0.68 (0.08)	0.66 (0.14)
1 December			0.66 (0.07)	

a/ Proportion ( $X=W_1/W_0$ ), where  $W_0$  and  $W_1$  represent the 30°C dry weights of samples initially and at time 1, respectively. Dry weight at time 0 was estimated from fresh to dry weight (30°C) ratios determined for separate random subsamples taken at the time of litter sample preparation.

b/ standard deviation

Table 5. Mean proportion<sup>a</sup> of initial overall mass (30°C) remaining at different times in 1985, for bulk red maple foliar litter samples disburshed in early December, 1984.

Sample Retrieval Date	Ground Site Plantation	Antenna Site	
		Plantation	Pole-stand
30 April	0.64 (0.05) <sup>b</sup>	0.70 (0.02)	0.71 (0.02)
2 June	0.59 (0.01)	0.63 (0.05)	0.63 (0.03)
3 July	0.55 (0.02)	0.59 (0.04)	0.69 (0.04)
31 July	0.52 (0.03)	0.54 (0.03)	0.64 (0.02)
27 August	0.45 (0.03)	0.53 (0.05)	0.60 (0.01)
31 October	0.40 (0.03)	0.45 (0.02)	0.55 (0.02)
2 November	0.40 (0.11)	0.46 (0.09)	0.54 (0.03)
1 December			0.52 (0.06)

Table 5. (cont)

Sample Retrieval Date	Control Site	
	Plantation	Pole-stand
30 April	0.70 (0.02)	0.72 (0.02)
2 June	0.62 (0.04)	0.65 (0.02)
3 July	0.57 (0.03)	0.64 (0.01)
31 July	0.56 (0.03)	0.64 (0.02)
27 August	0.50 (0.03)	0.58 (0.02)
31 October	0.53 (0.08)	0.54 (0.03)
2 November	0.48 (0.07)	0.51 (0.02)
1 December		0.47 (0.03)

a/ Proportion ( $X=W_1/W_0$ ), where  $W_0$  and  $W_1$  represent the 30°C dry weights of samples initially and at time 1, respectively. Dry weight at time 0 was estimated from fresh to dry weight (30°C) ratios determined for separate random subsamples taken at the time of litter sample preparation. These samples were also used to determine initial nutrient content.

b/ standard deviation

Table 6. Mean proportion<sup>a</sup> of initial overall mass (30°C) remaining at different times in 1985, for tethered red maple foliar litter samples disbursed in early December, 1984.

Sample Retrieval Date	Ground Site Plantation	Antenna Site	
		Plantation	Pole-stand
30 April	0.69 (0.09) <sup>b</sup>	0.71 (0.07)	0.71 (0.07)
2 June	0.60 (0.09)	0.63 (0.11)	0.64 (0.07)
3 July	0.52 (0.12)	0.57 (0.11)	0.67 (0.06)
31 July	0.51 (0.12)	0.54 (0.11)	0.64 (0.06)
27 August	0.45 (0.17)	0.50 (0.14)	0.60 (0.07)
31 October	0.32 (0.16)	0.41 (0.16)	0.61 (0.09)
2 November	0.38 (0.15)	0.41 (0.17)	0.53 (0.10)
1 December			0.53 (0.07)

Table 6. (cont)

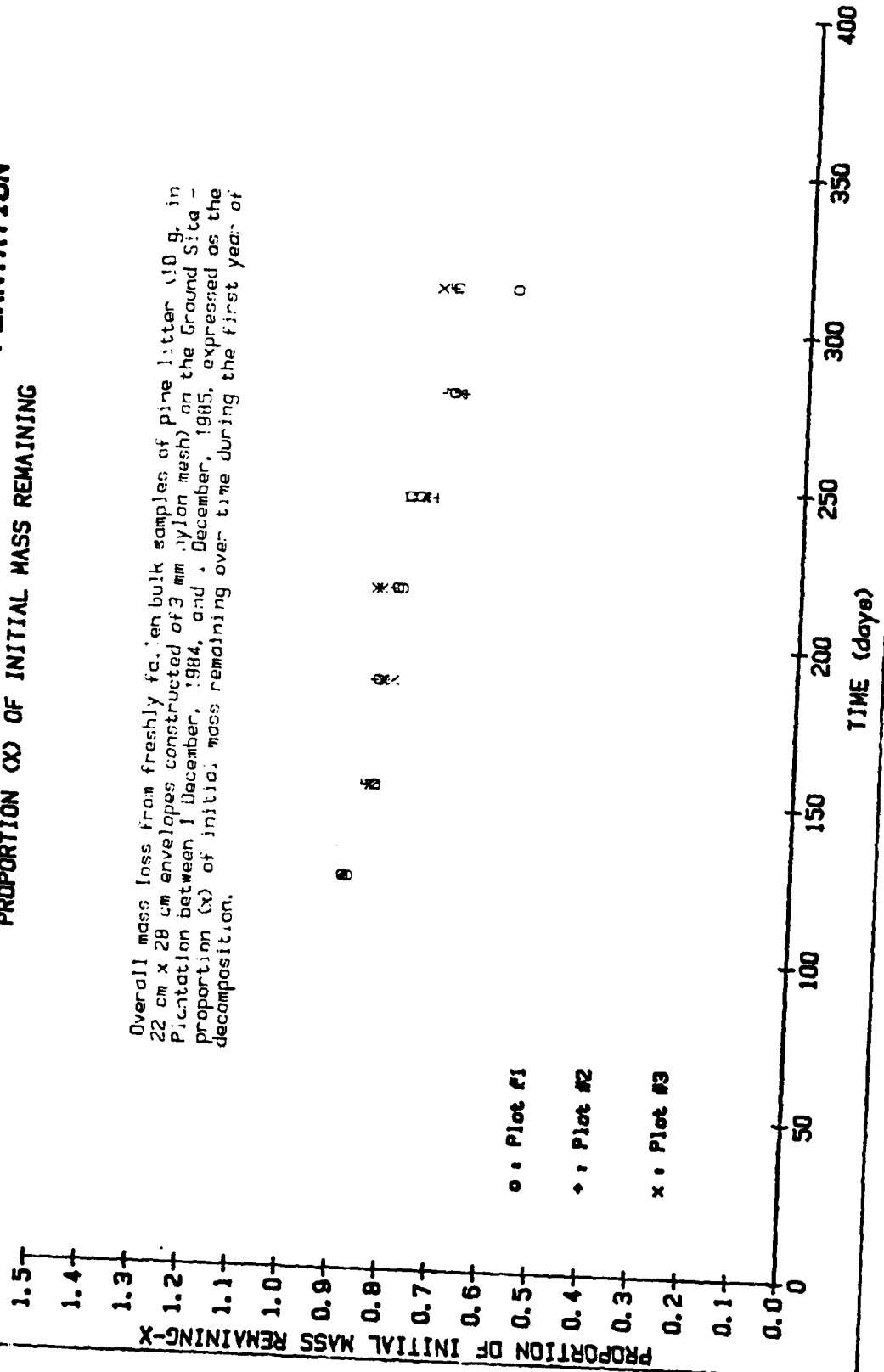
Sample Retrieval Date	Control Site	
	Plantation	Pole-stand
30 April	0.71 (0.07)	0.71 (0.07)
2 June	0.64 (0.16)	0.66 (0.08)
3 July	0.59 (0.10)	0.65 (0.08)
31 July	0.55 (0.13)	0.60 (0.08)
27 August	0.59 (0.11)	0.56 (0.12)
31 October	0.50 (0.12)	0.44 (0.11)
2 November	0.45 (0.16)	0.51 (0.14)
1 December		0.55 (0.08)

<sup>a</sup>/ Proportion ( $X=W_1/W_0$ ), where  $W_0$  and  $W_1$  represent the 30°C dry weights of samples initially and at time 1, respectively. Dry weight at time 0 was estimated from fresh to dry weight (30°C) ratios determined for separate random subsamples taken at the time of litter sample preparation. These samples were also used to determine initial nutrient content.

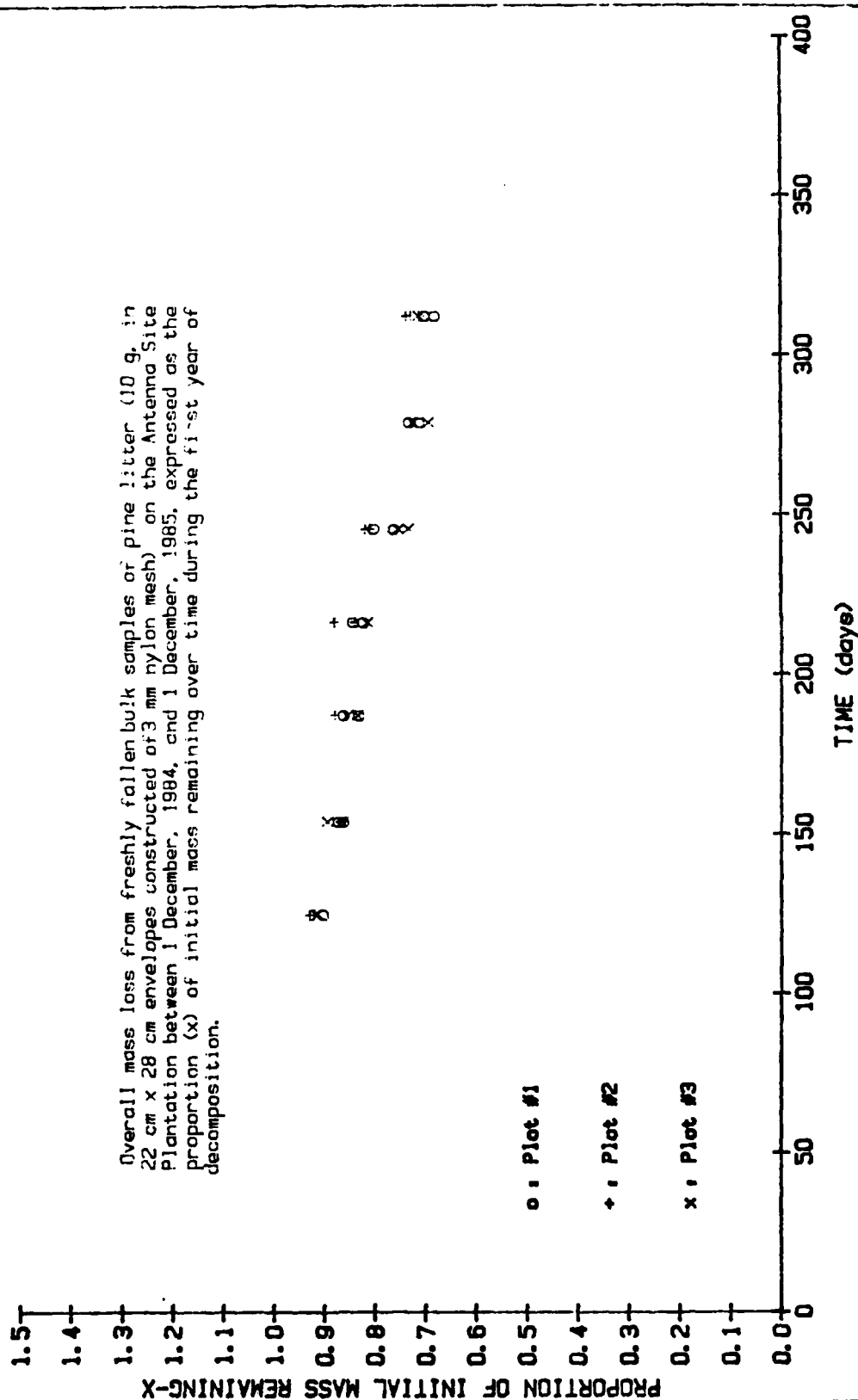
<sup>b</sup>/ standard deviation

**FIGURE 1. BULK PINE LITTER, GROUND SITE - PLANTATION**  
**PROPORTION OF INITIAL MASS REMAINING**

Overall mass loss from freshly fallen bulk samples of pine litter (10 g. in 22 cm x 28 cm envelopes constructed of 3 mm nylon mesh) on the Ground Site - Plantation between 1 December, 1984, and 1 December, 1985, expressed as the proportion (x) of initial mass remaining over time during the first year of decomposition.



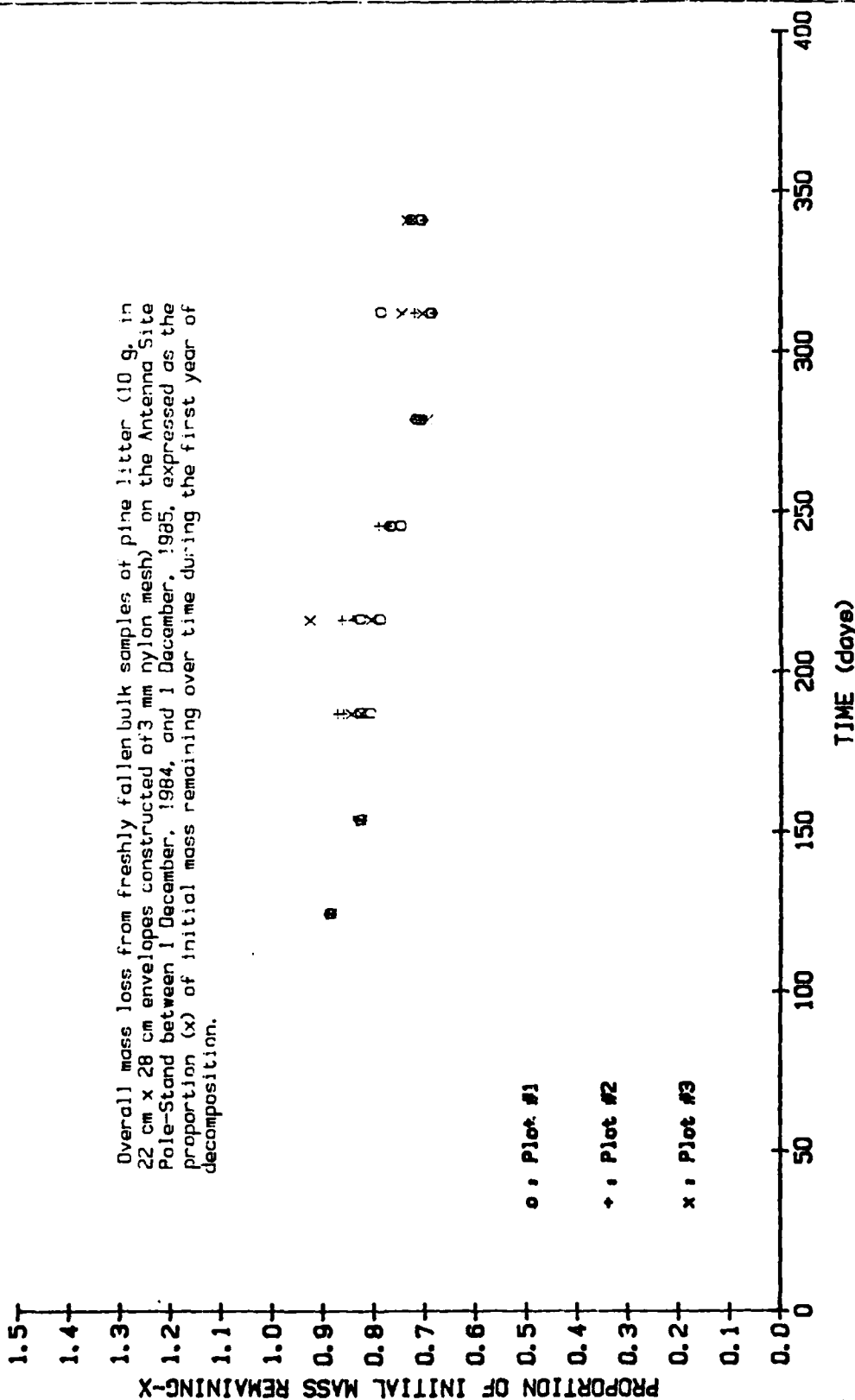
**FIGURE 2. BULK PINE LITTER, ANTENNA SITE - PLANTATION**  
**PROPORTION (X) OF INITIAL MASS REMAINING**



**FIGURE 3. BULK PINE LITTER, ANTENNA SITE - POLE-STAND**

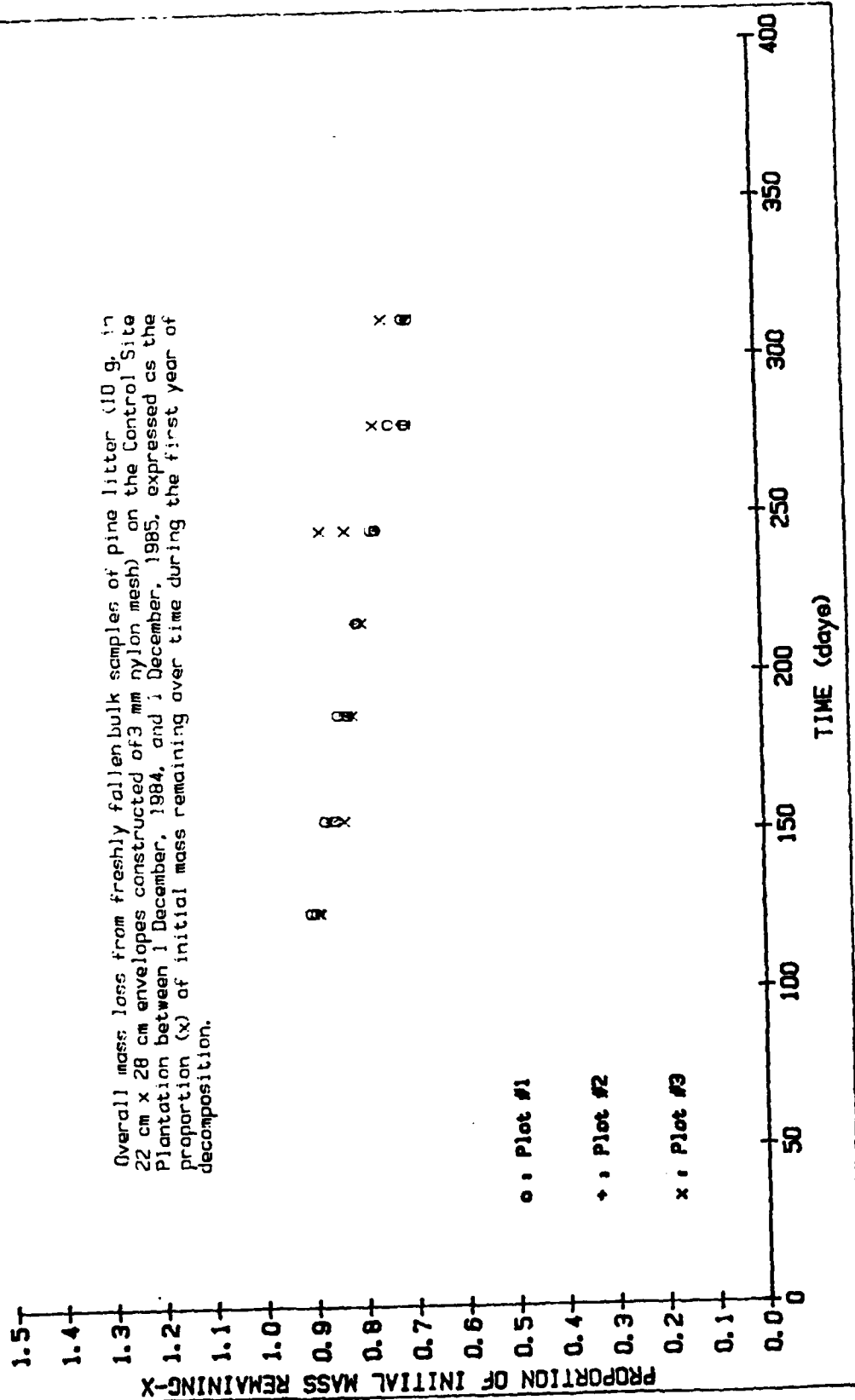
PROPORTION (X) OF INITIAL MASS REMAINING

Overall mass loss from freshly fallen bulk samples of pine litter (10 g. in 22 cm x 28 cm envelopes constructed of 3 mm nylon mesh) on the Antenna Site Pole-Stand between 1 December, 1984, and 1 December, 1985, expressed as the proportion (x) of initial mass remaining over time during the first year of decomposition.



**FIGURE 4. BULK PINE LITTER, CONTROL SITE - PLANTATION**  
**PROPORTION (%) OF INITIAL MASS REMAINING**

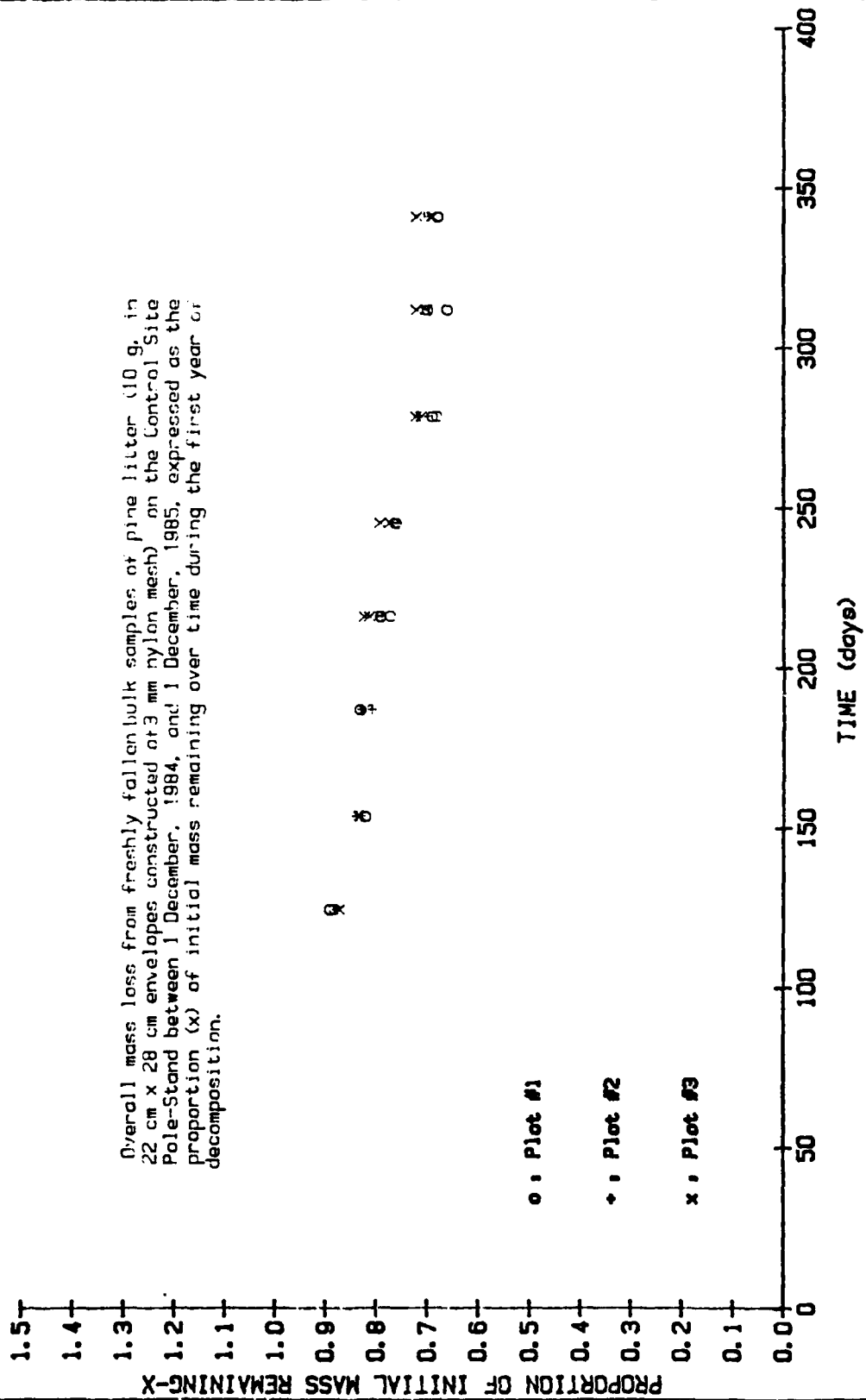
Overall mass loss from freshly fallen bulk samples of pine litter (10 g. in 22 cm x 28 cm envelopes constructed of 3 mm nylon mesh) on the Control Site Plantation between 1 December, 1984, and 1 December, 1985, expressed as the proportion (%) of initial mass remaining over time during the first year of decomposition.





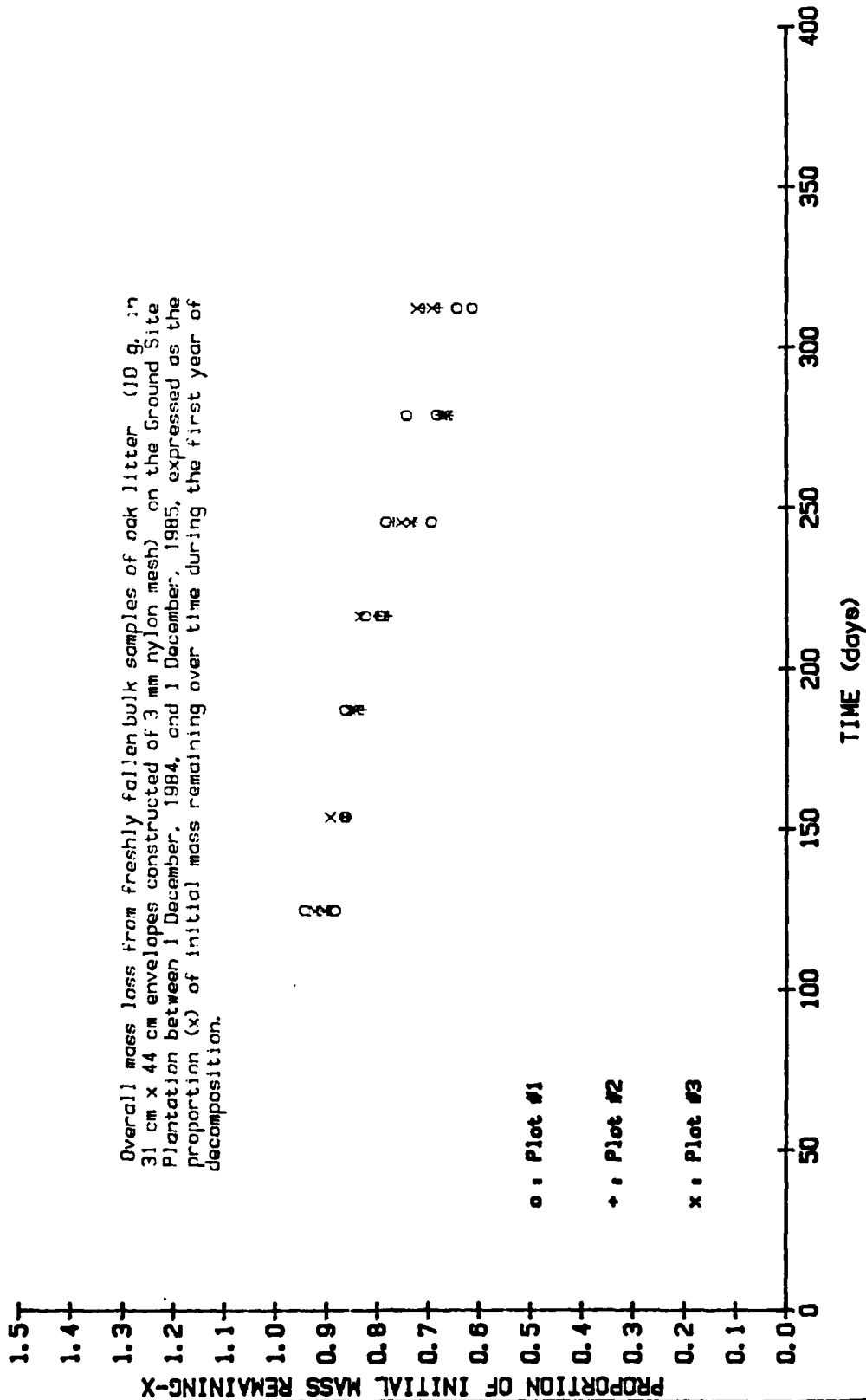
**FIGURE 5. BULK PINE LITTER, CONTROL SITE - POLE-STAND**  
**PROPORTION (x) OF INITIAL MASS REMAINING**

Overall mass loss from freshly fallen bulk samples of pine litter (10 g. in 22 cm x 28 cm envelopes constructed of 3 mm nylon mesh) on the Control Site Pole-stand between 1 December, 1984, and 1 December, 1985, expressed as the proportion (x) of initial mass remaining over time during the first year of decomposition.



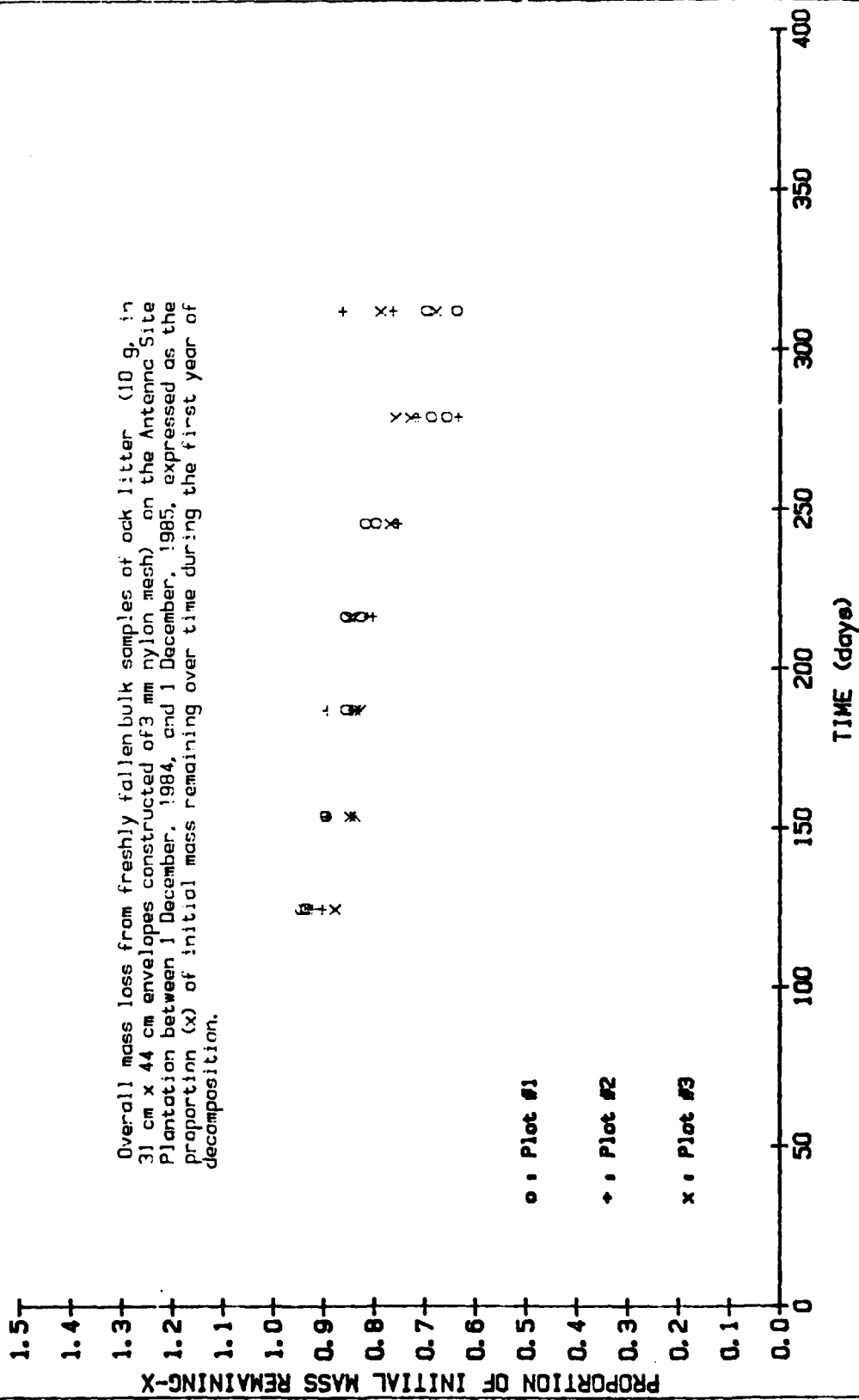
**FIGURE 6. BULK OAK LITTER, GROUND SITE - PLANTATION**  
**PROPORTION (X) OF INITIAL MASS REMAINING**

Overall mass loss from freshly fallen bulk samples of oak litter (10 g, in 31 cm x 44 cm envelopes constructed of 3 mm nylon mesh) on the Ground Site Plantation between 1 December, 1984, and 1 December, 1985, expressed as the proportion (x) of initial mass remaining over time during the first year of decomposition.



**FIGURE 7. BULK OAK LITTER, ANTENNA SITE - PLANTATION**  
**PROPORTION (X) OF INITIAL MASS REMAINING**

Overall mass loss from freshly fallen bulk samples of oak litter (10 g. in 31 cm x 44 cm envelopes constructed of 3 mm nylon mesh) on the Antenna Site Plantation between 1 December, 1984, and 1 December, 1985, expressed as the proportion (x) of initial mass remaining over time during the first year of decomposition.



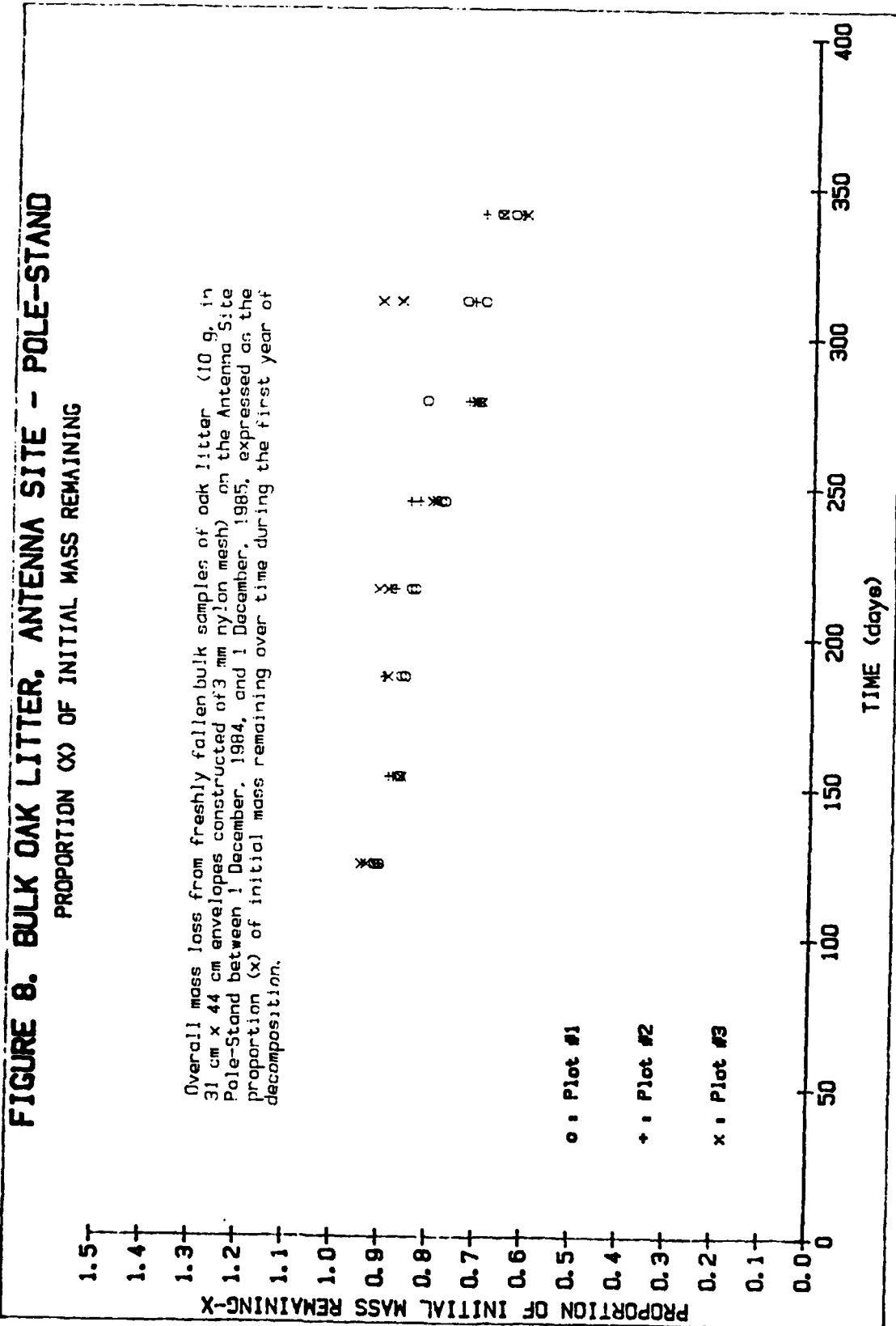


FIGURE 9. BULK OAK LITTER, CONTROL SITE - PLANTATION

PROPORTION (X) OF INITIAL MASS REMAINING

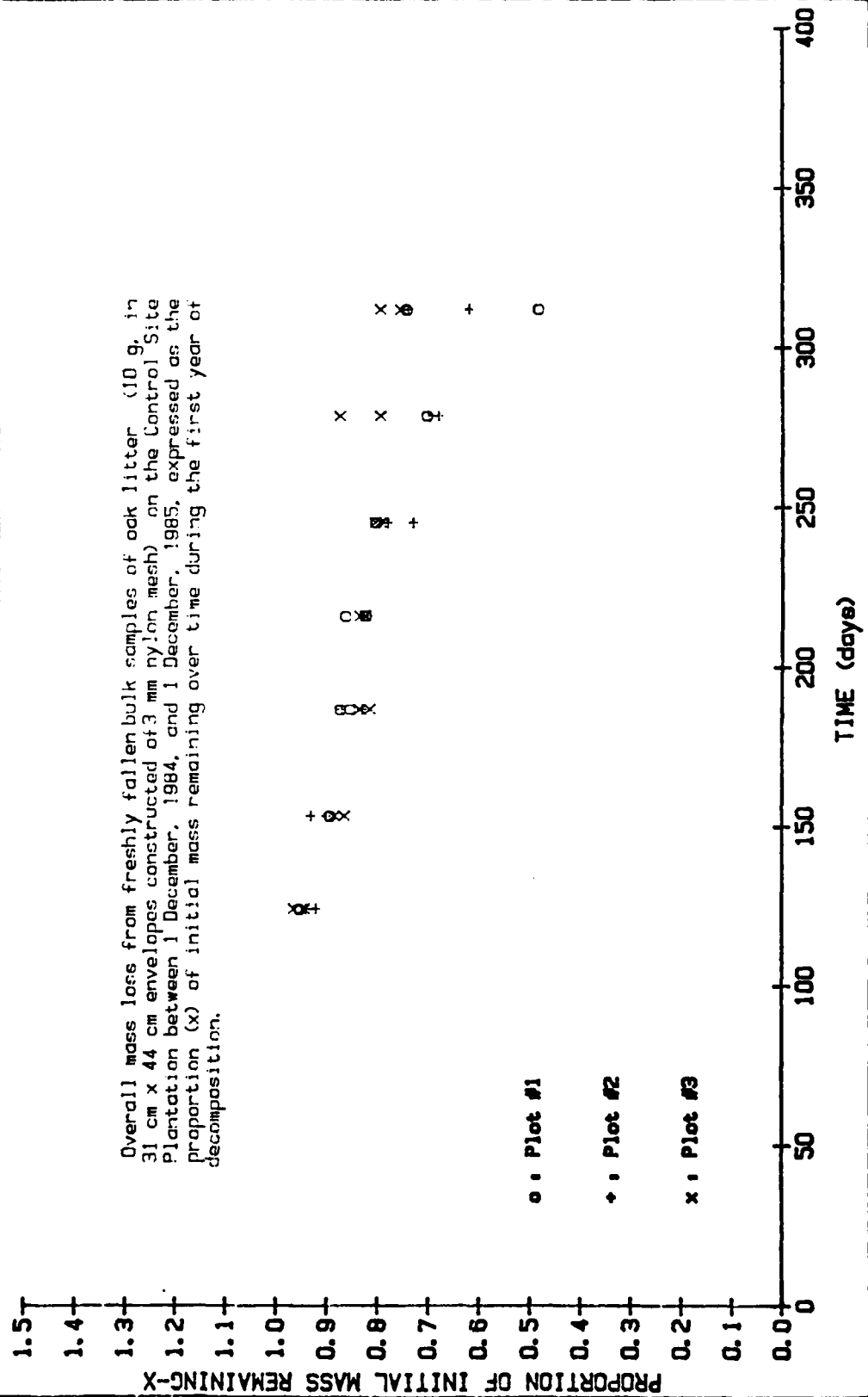
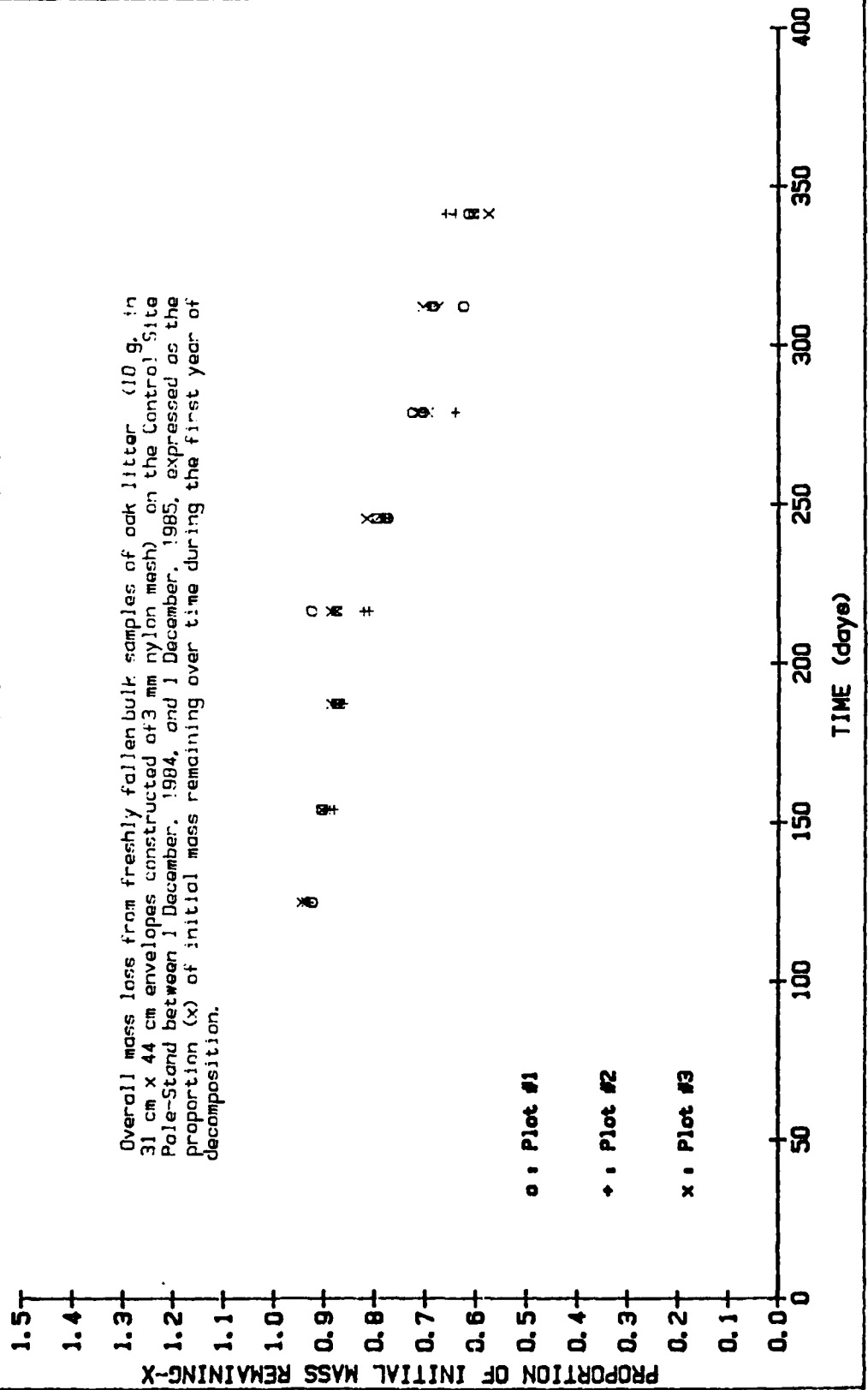


FIGURE 10. BULK OAK LITTER, CONTROL SITE - POLE-STAND

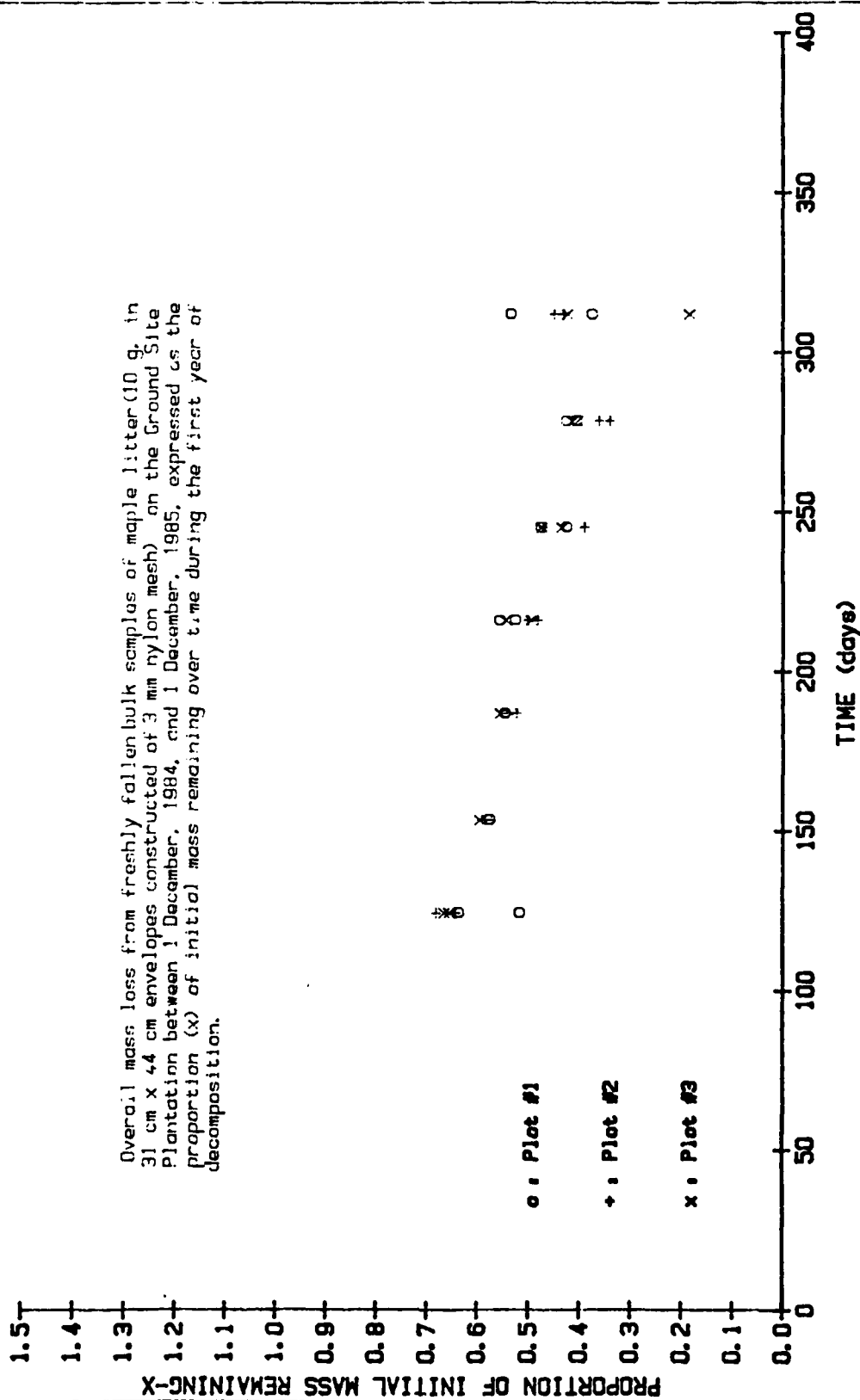
PROPORTION (X) OF INITIAL MASS REMAINING



**FIGURE 11. BULK MAPLE LITTER, GROUND SITE - PLANTATION**

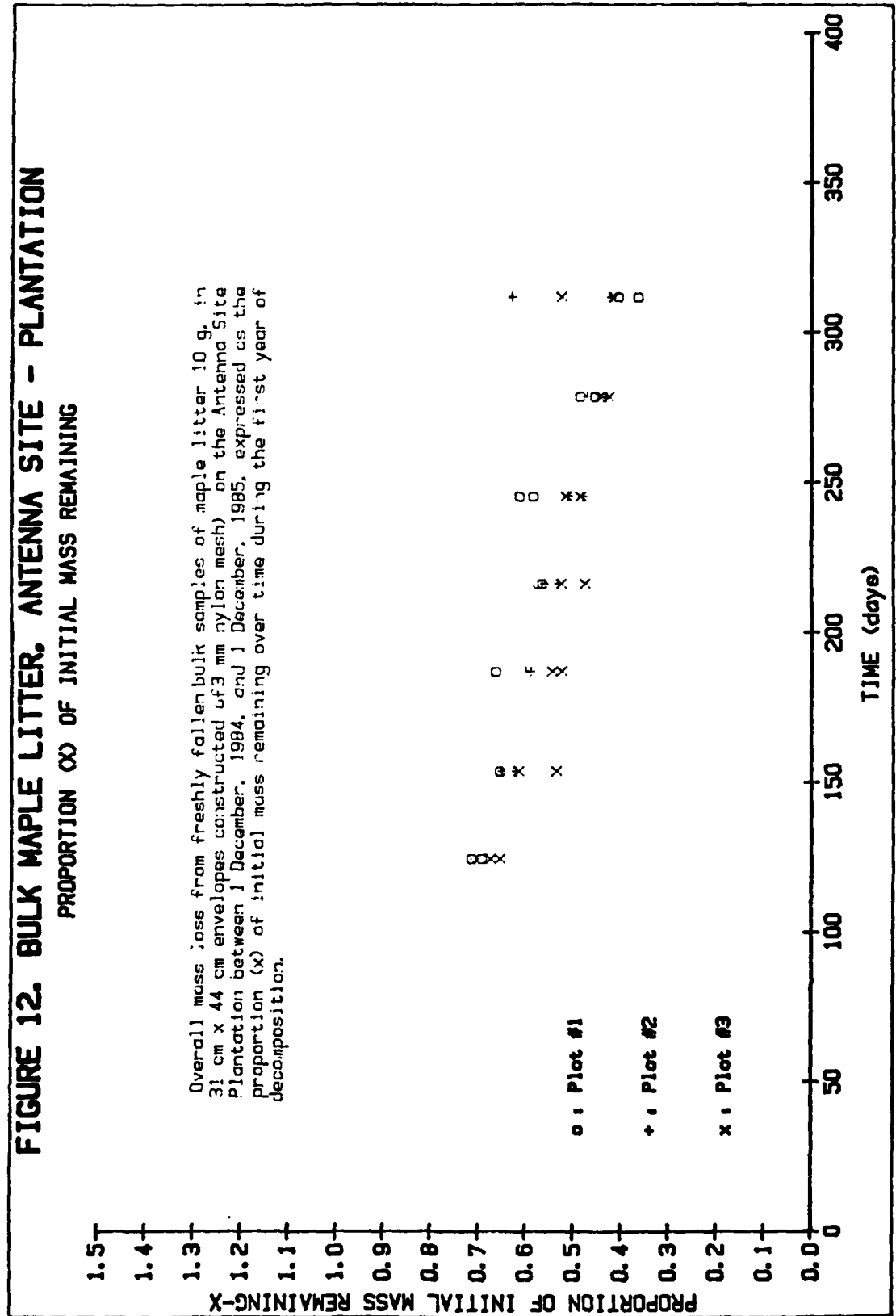
PROPORTION (X) OF INITIAL MASS REMAINING

Overall mass loss from freshly fallen bulk samples of maple litter (10 g. in 31 cm x 44 cm envelopes constructed of 3 mm nylon mesh) on the Ground Site Plantation between 1 December, 1984, and 1 December, 1985, expressed as the proportion (x) of initial mass remaining over time during the first year of decomposition.



**FIGURE 12. BULK MAPLE LITTER, ANTENNA SITE - PLANTATION**  
**PROPORTION (X) OF INITIAL MASS REMAINING**

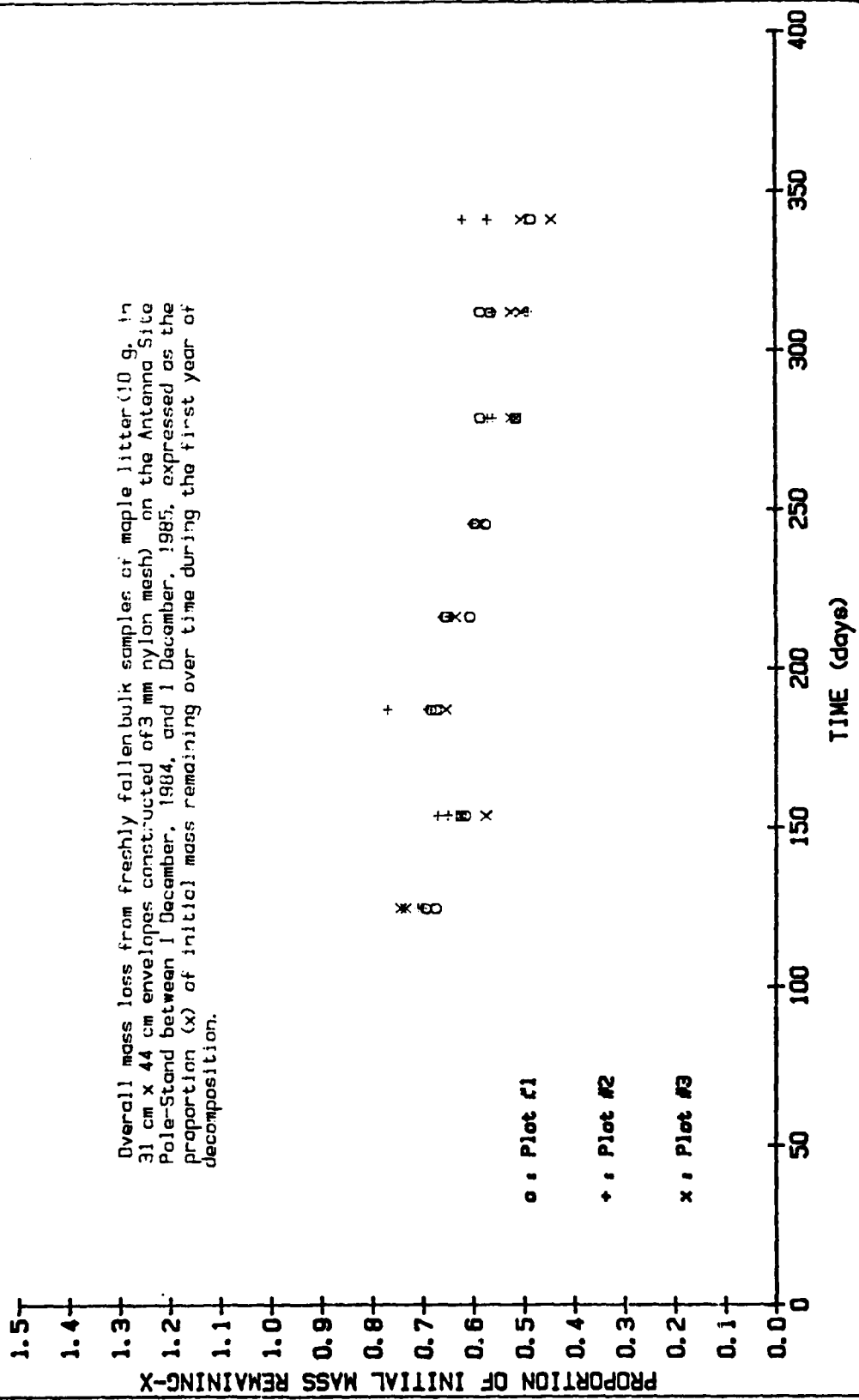
Overall mass loss from freshly fallen bulk samples of maple litter 10 g. in 31 cm x 44 cm envelopes constructed of 3 mm nylon mesh) on the Antenna Site Plantation between 1 December, 1984, and 1 December, 1985, expressed as the proportion (x) of initial mass remaining over time during the first year of decomposition.



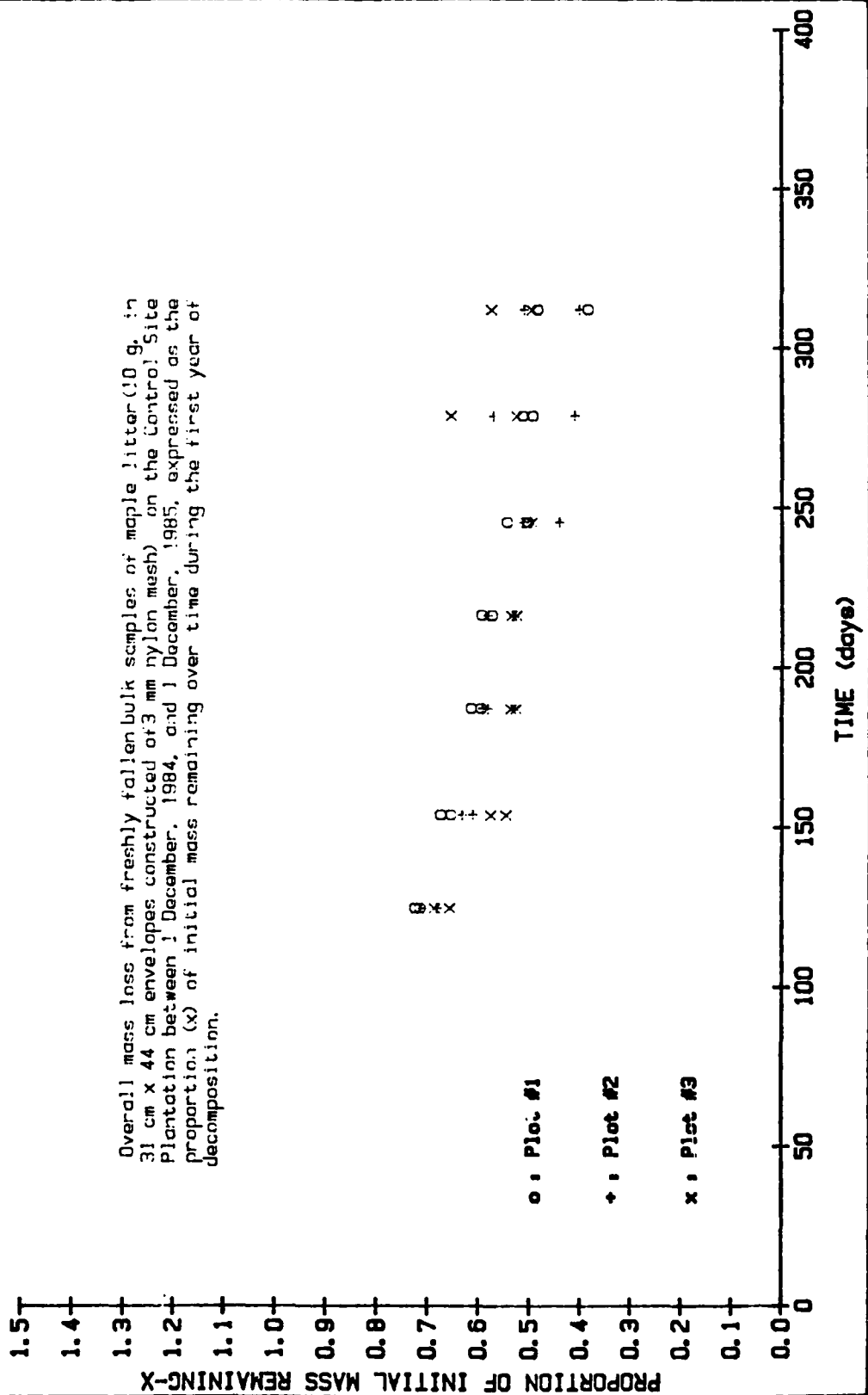


**FIGURE 13. BULK MAPLE LITTER, ANTENNA SITE - POLE-STAND**  
**PROPORTION (x) OF INITIAL MASS REMAINING**

Overall mass loss from freshly fallen bulk samples of maple litter (10 g. in 31 cm x 44 cm envelopes constructed of 3 mm nylon mesh) on the Antenna Site Pole-Stand between 1 December, 1984, and 1 December, 1985, expressed as the proportion (x) of initial mass remaining over time during the first year of decomposition.

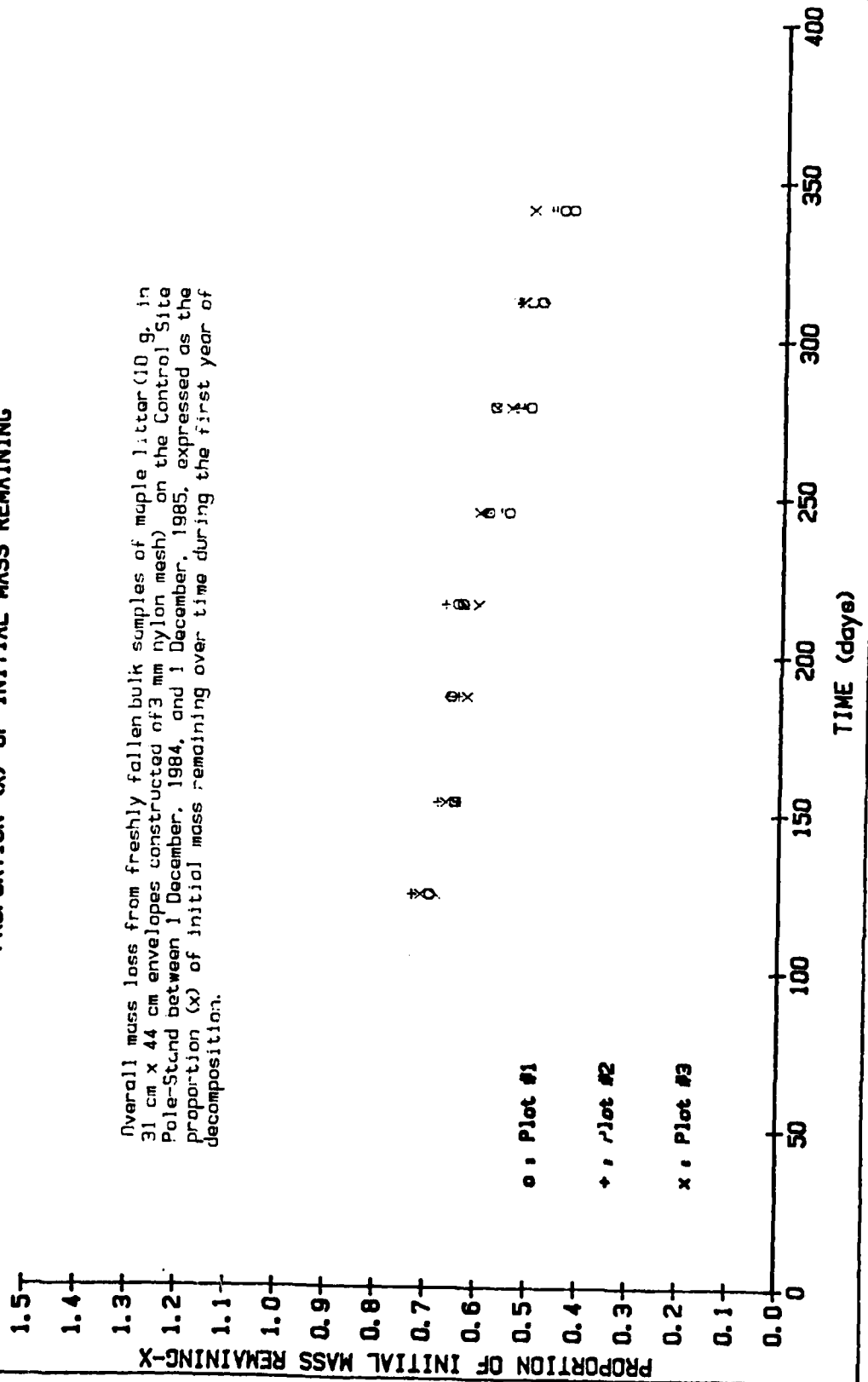


**FIGURE 14. BULK MAPLE LITTER, CONTROL SITE - PLANTATION**  
**PROPORTION (x) OF INITIAL MASS REMAINING**



**FIGURE 15. BULK MAPLE LITTER, CONTROL SITE - POLE-STAND**  
**PROPORTION (X) OF INITIAL MASS REMAINING**

Overall mass loss from freshly fallen bulk samples of maple litter (10 g. in 31 cm x 44 cm envelopes constructed of 3 mm nylon mesh) on the Control Site Pole-Stand between 1 December, 1984, and 1 December, 1985, expressed as the proportion (x) of initial mass remaining over time during the first year of decomposition.



- Figure 16. Total mass loss by individual pine fascicles on the Ground site plantation between 1 December, 1984, and 1 December, 1985.
- Figure 17. Total mass loss by individual pine fascicles on the Antenna site plantation between 1 December, 1984, and 1 December, 1985.
- Figure 18. Total mass loss by individual pine fascicles in the Antenna site pole-stand between 1 December, 1984, and 1 December, 1985.
- Figure 19. Total mass loss by individual pine fascicles on the Control site plantation between 1 December, 1984, and 1 December, 1985.
- Figure 20. Total mass loss by individual pine fascicles in the Control site pole-stand between 1 December, 1984, and 1 December, 1985.
- Figure 21. Total mass loss by individual oak leaves on the Ground site plantation between 1 December, 1984, and 1 December, 1985.
- Figure 22. Total mass loss by individual oak leaves on the Antenna site plantation between 1 December, 1984, and 1 December, 1985.
- Figure 23. Total mass loss by individual oak leaves in the Antenna site pole-stand between 1 December, 1984, and 1 December, 1985.
- Figure 24. Total mass loss by individual oak leaves on the Control site plantation between 1 December, 1984, and 1 December, 1985.
- Figure 25. Total mass loss by individual oak leaves in the Control site pole-stand between 1 December, 1984, and 1 December, 1985.
- Figure 26. Total mass loss by individual maple leaves on the Ground site plantation between 1 December, 1984, and 1 December, 1985.
- Figure 27. Total mass loss by individual maple leaves on the Antenna site plantation between 1 December, 1984, and 1 December, 1985.
- Figure 28. Total mass loss by individual maple leaves in the Antenna site pole-stand between 1 December, 1984, and 1 December, 1985.
- Figure 29. Total mass loss by individual maple leaves on the Control site plantation between 1 December, 1984, and 1 December, 1985.
- Figure 30. Total mass loss by individual maple leaves in the Control site pole-stand between 1 December, 1984, and 1 December, 1985.
- Figure 31. Total mass loss by unbagged individual pine fascicles on Control site plantation plot 311 between 1 December, 1984, and 1 December, 1985.
- Figure 32. Total mass loss by unbagged individual oak leaves in Control site pole-stand plot 321 between 1 December, 1984, and 1 December, 1985.

Figure 16.  
**PINE FASCICLES, GROUND PLANTATION**  
**PROPORTION OF INITIAL MASS REMAINING**

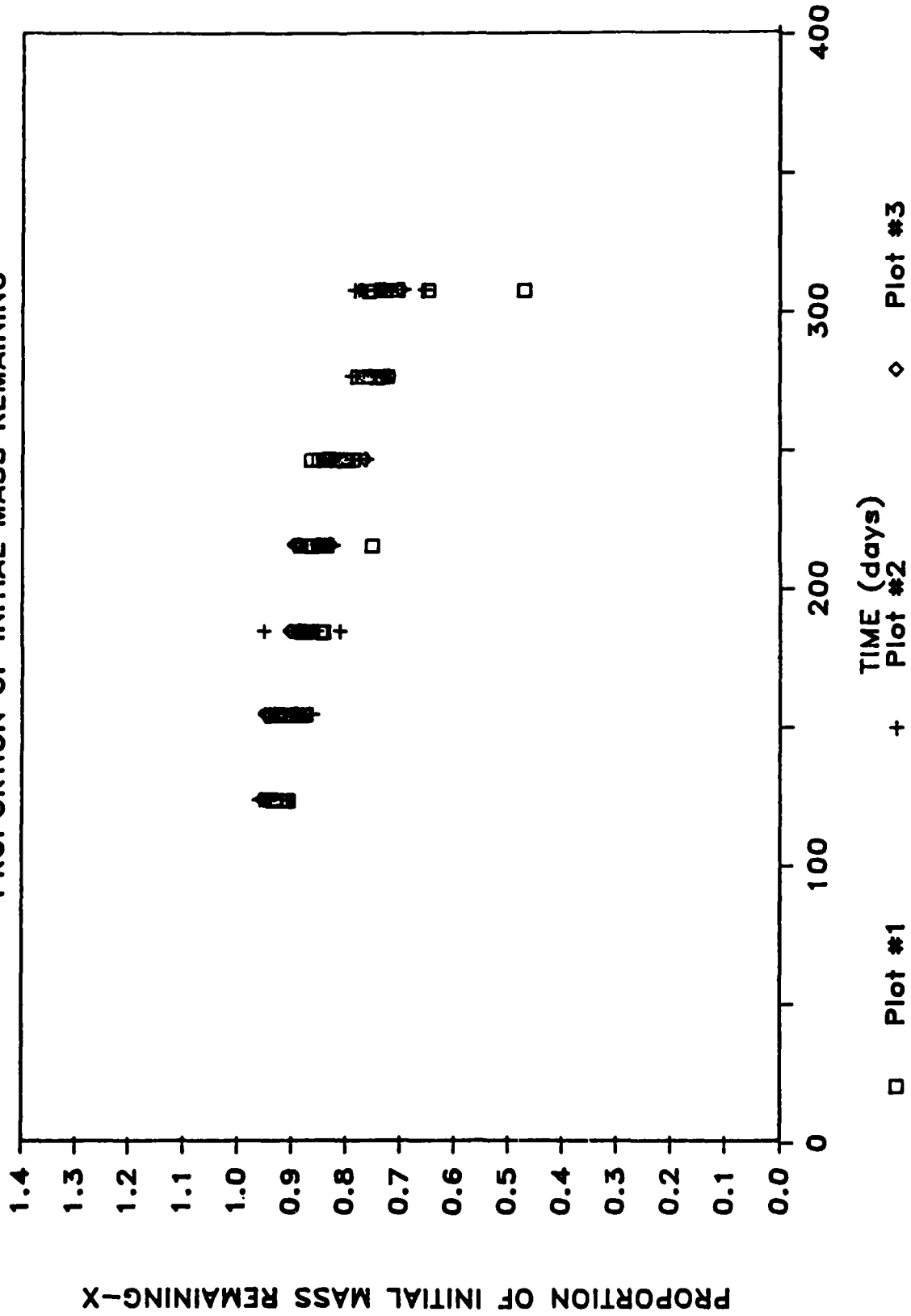


Figure 17. PINE FASCICLES, ANTENNA PLANTATION  
PROPORTION OF INITIAL MASS REMAINING

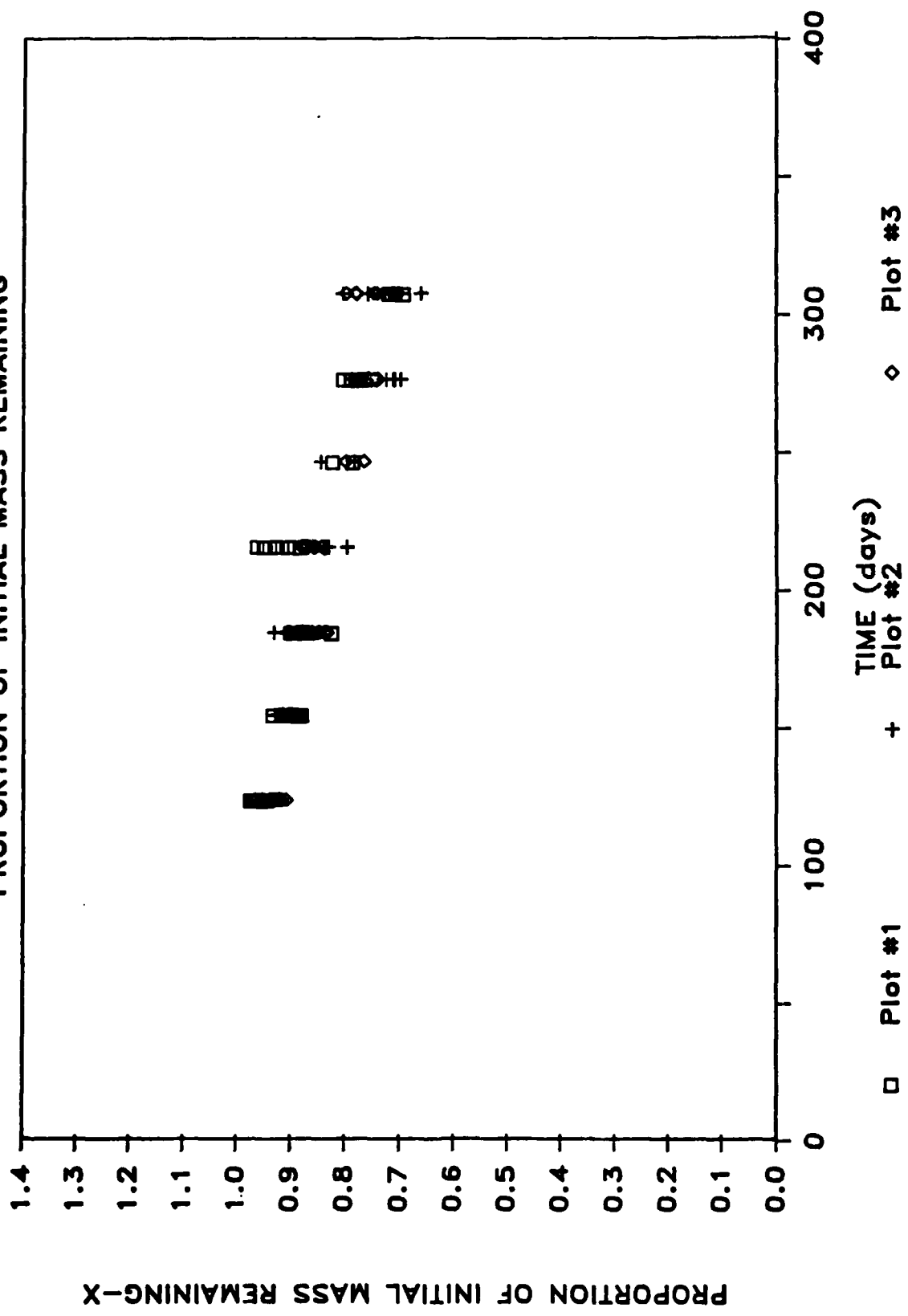


Figure 18. PINE FASCILES, ANTENNA POLE-STAND  
PROPORTION OF INITIAL MASS REMAINING

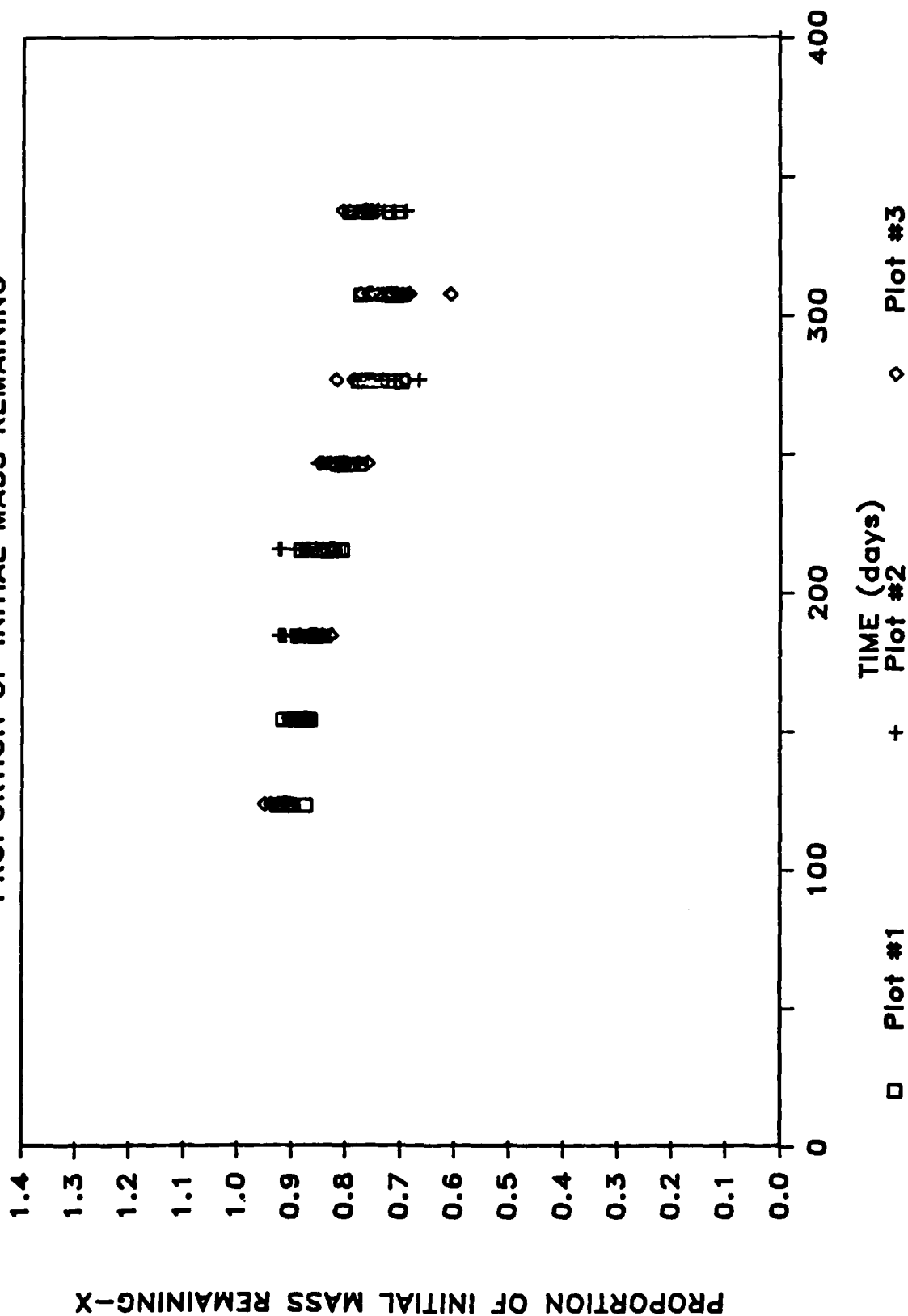


Figure 19. PINE FASCICLES, CONTROL PLANTATION  
PROPORTION OF INITIAL MASS REMAINING

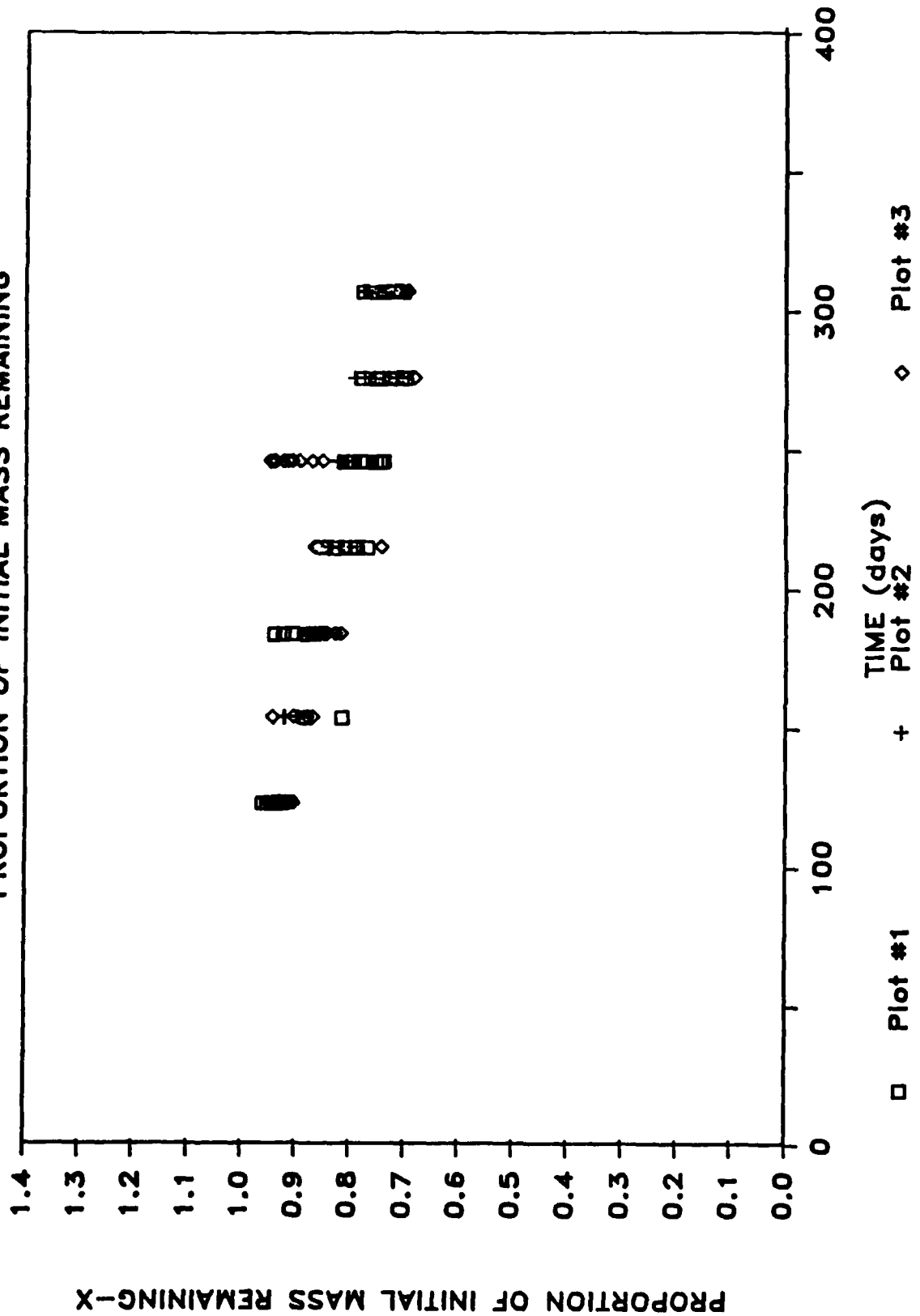




Figure 20.

# PINE FASCICLES, CONTROL POLE-STAND

PROPORTION OF INITIAL MASS REMAINING

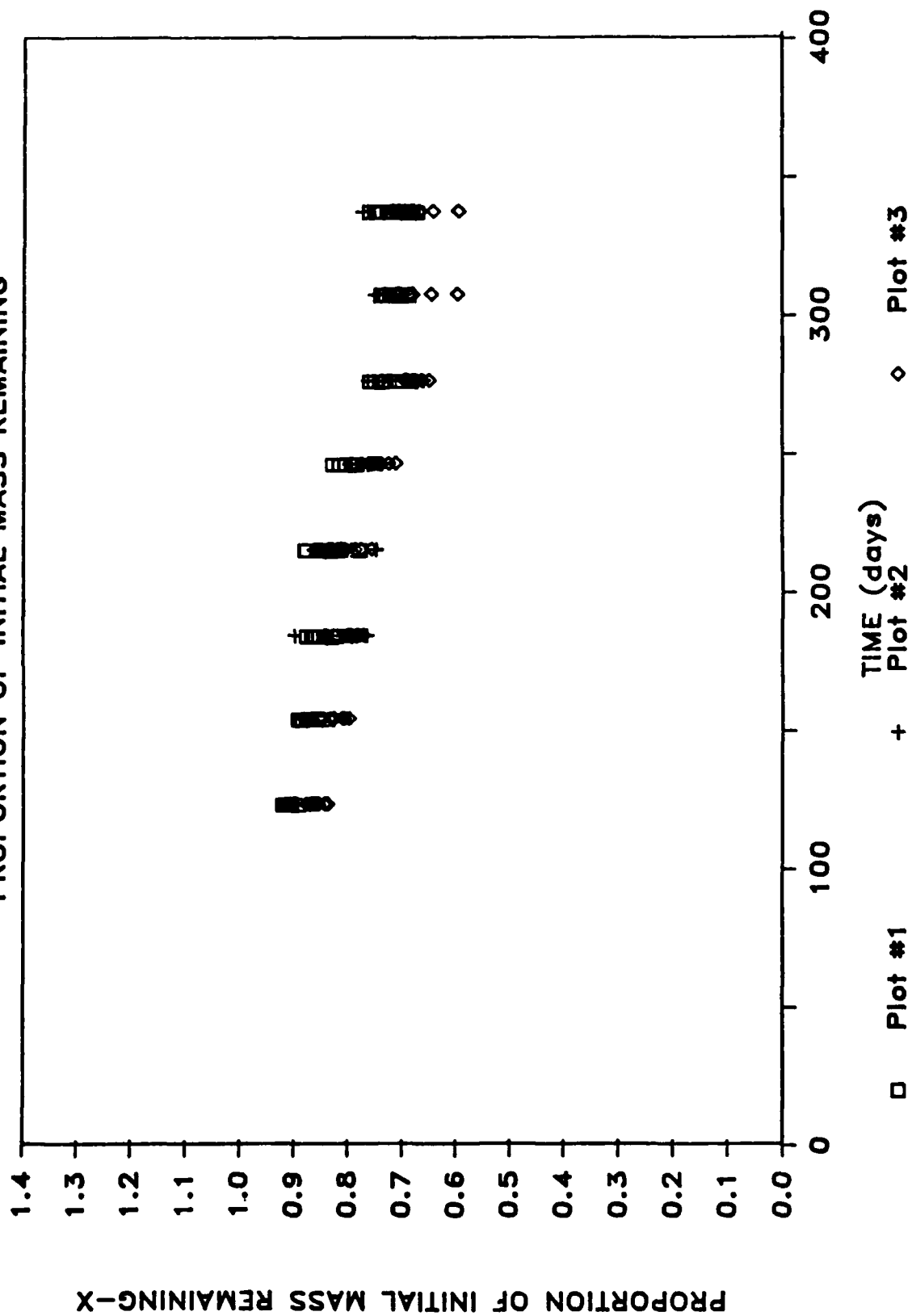
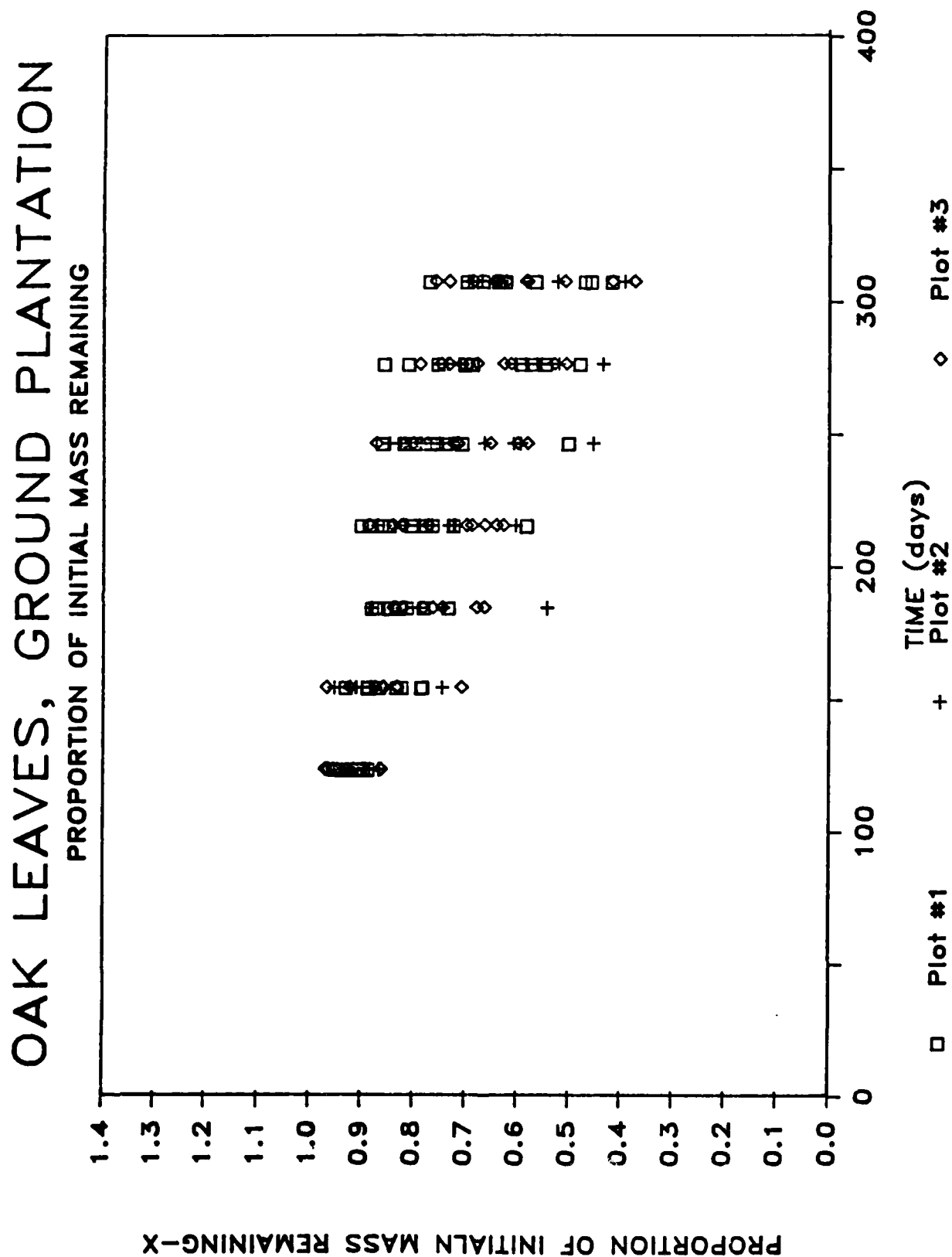


Figure 21.



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COMPILATION OF 1985 ANNUAL REPORTS OF THE NAVY ELF  
(EXTREMELY LOW FREQUENCY) RESEARCH INST. CHICAGO  
IL C BECKER ET AL. JUL 86 IIRI-E86349-26-VOL-1

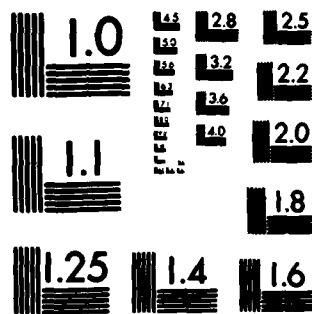
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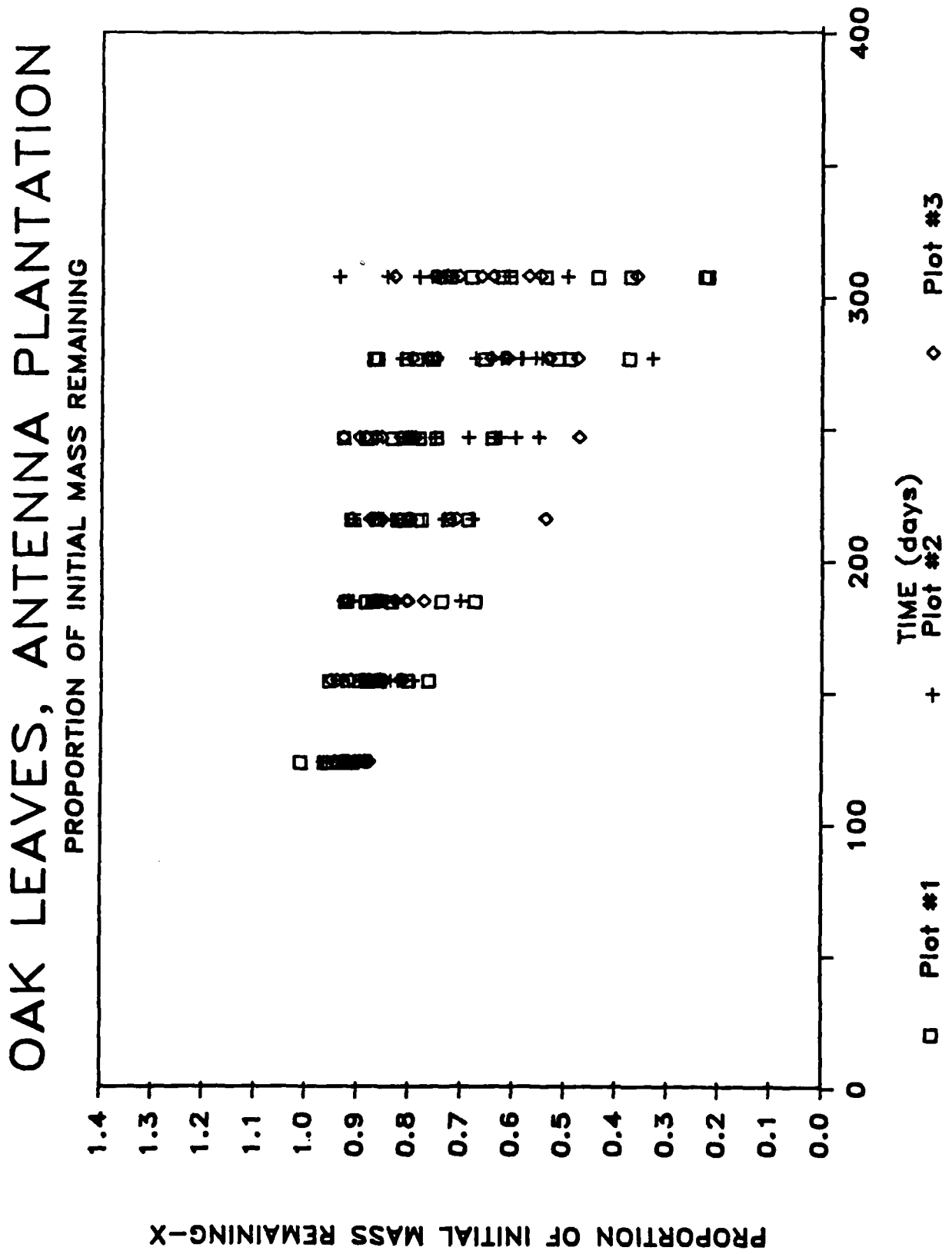
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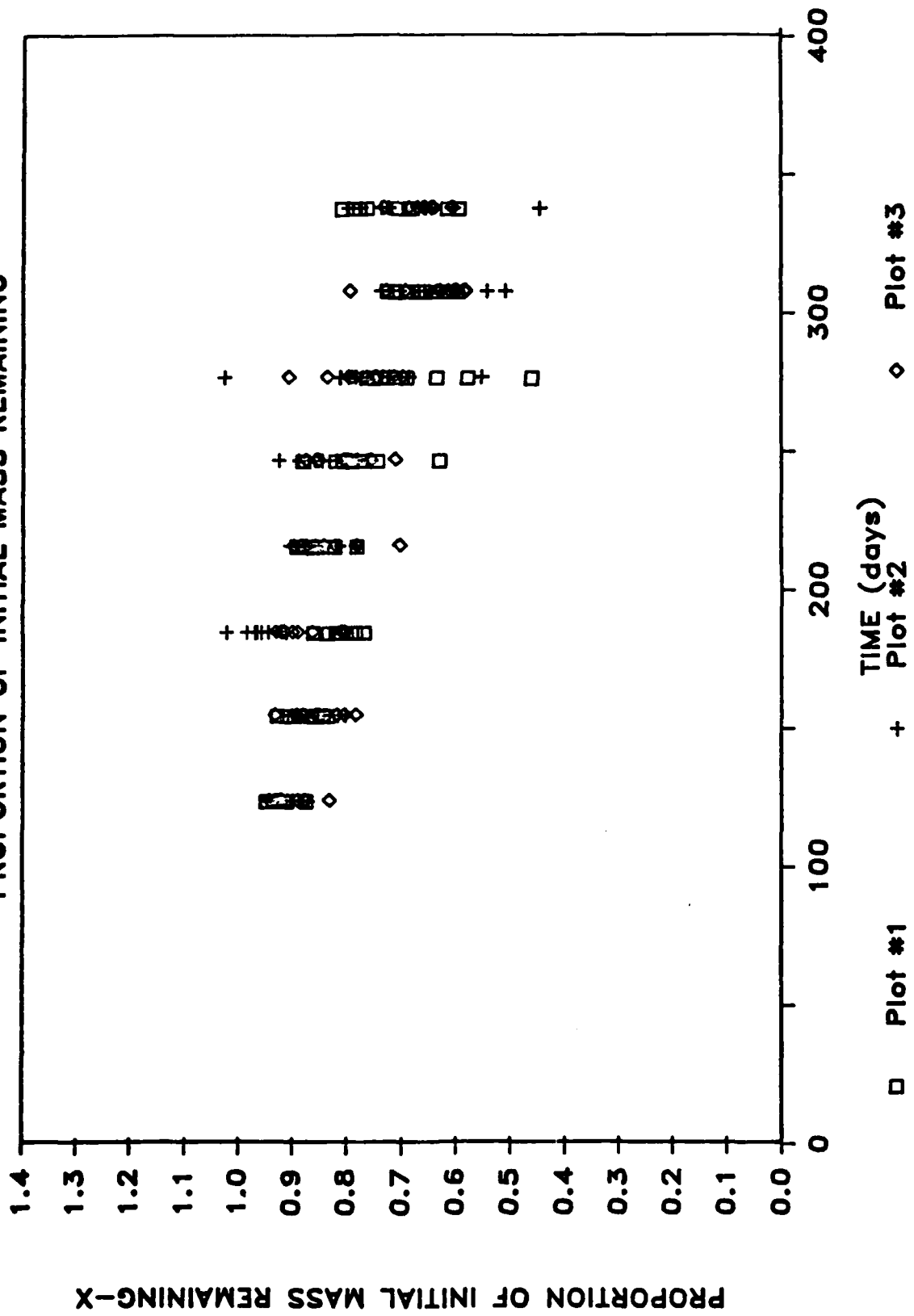


MICROCOPY RESOLUTION TEST CHART  
NATIONAL BUREAU OF STANDARDS-1963-A

Figure 22.



**OAK LEAVES, ANTENNA POLE-STAND  
PROPORTION OF INITIAL MASS REMAINING**



# OAK LEAVES, CONTROL PLANTATION

PROPORTION OF INITIAL MASS REMAINING

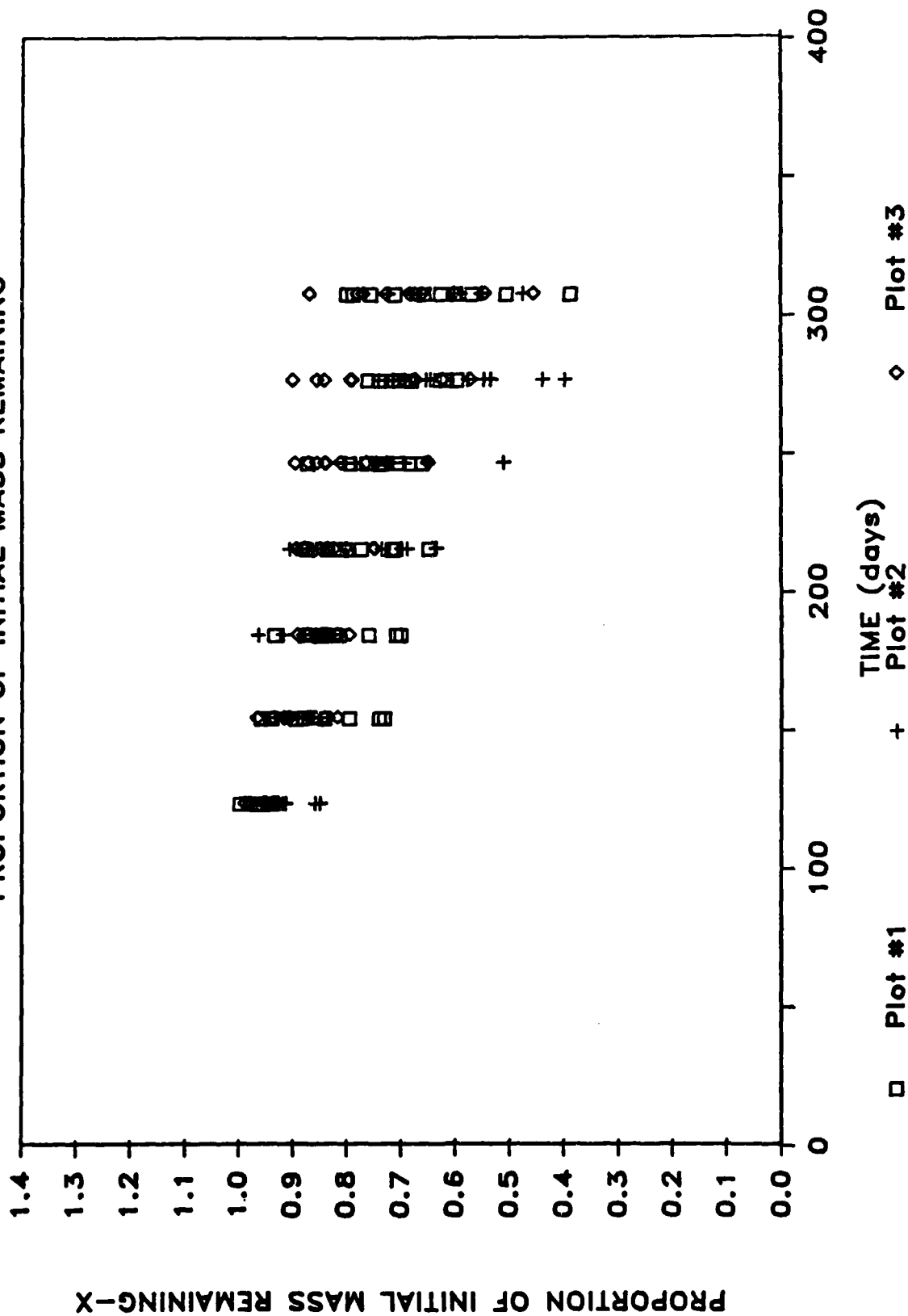
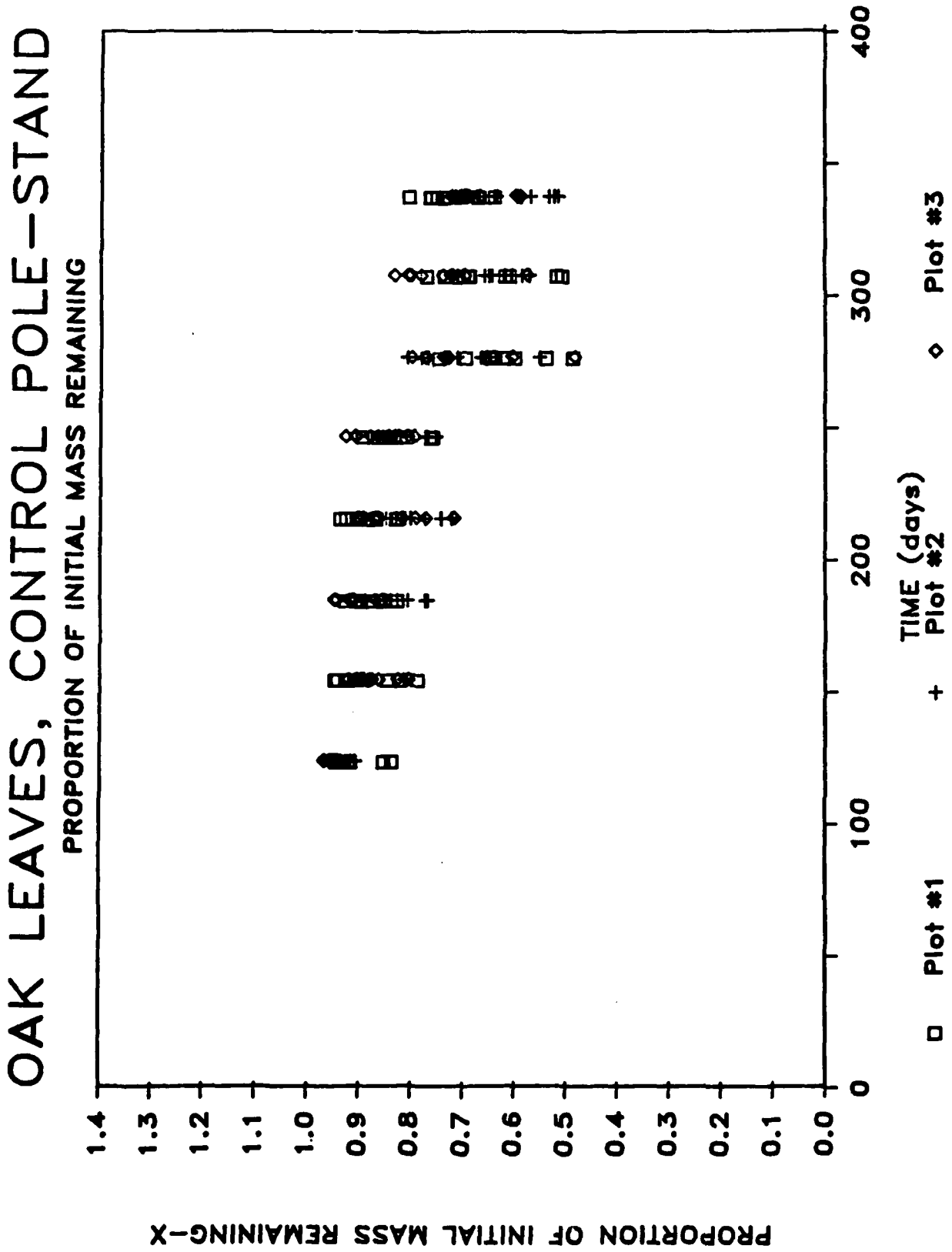


Figure 24.

Figure 25.





**Figure 26.**

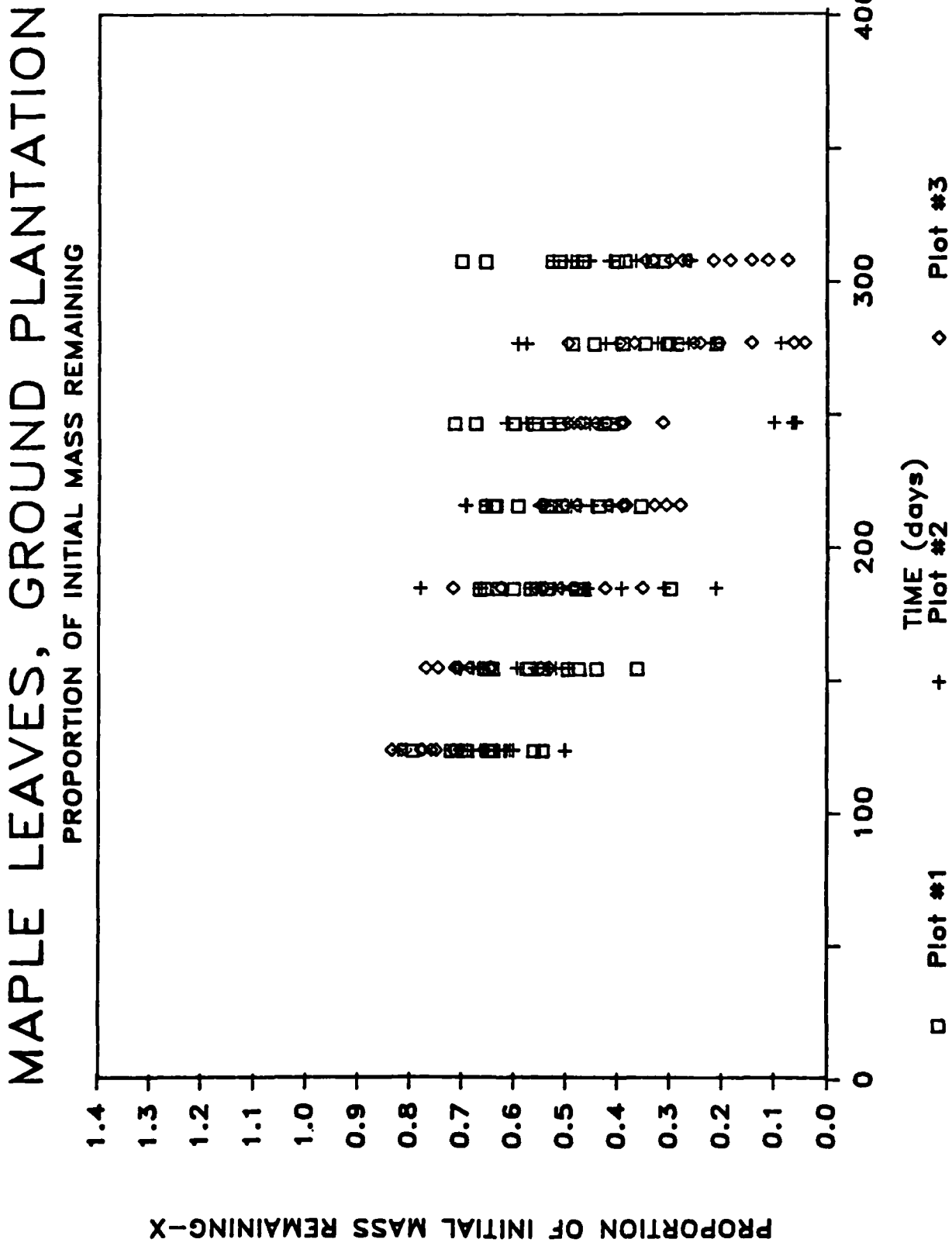


Figure 27.

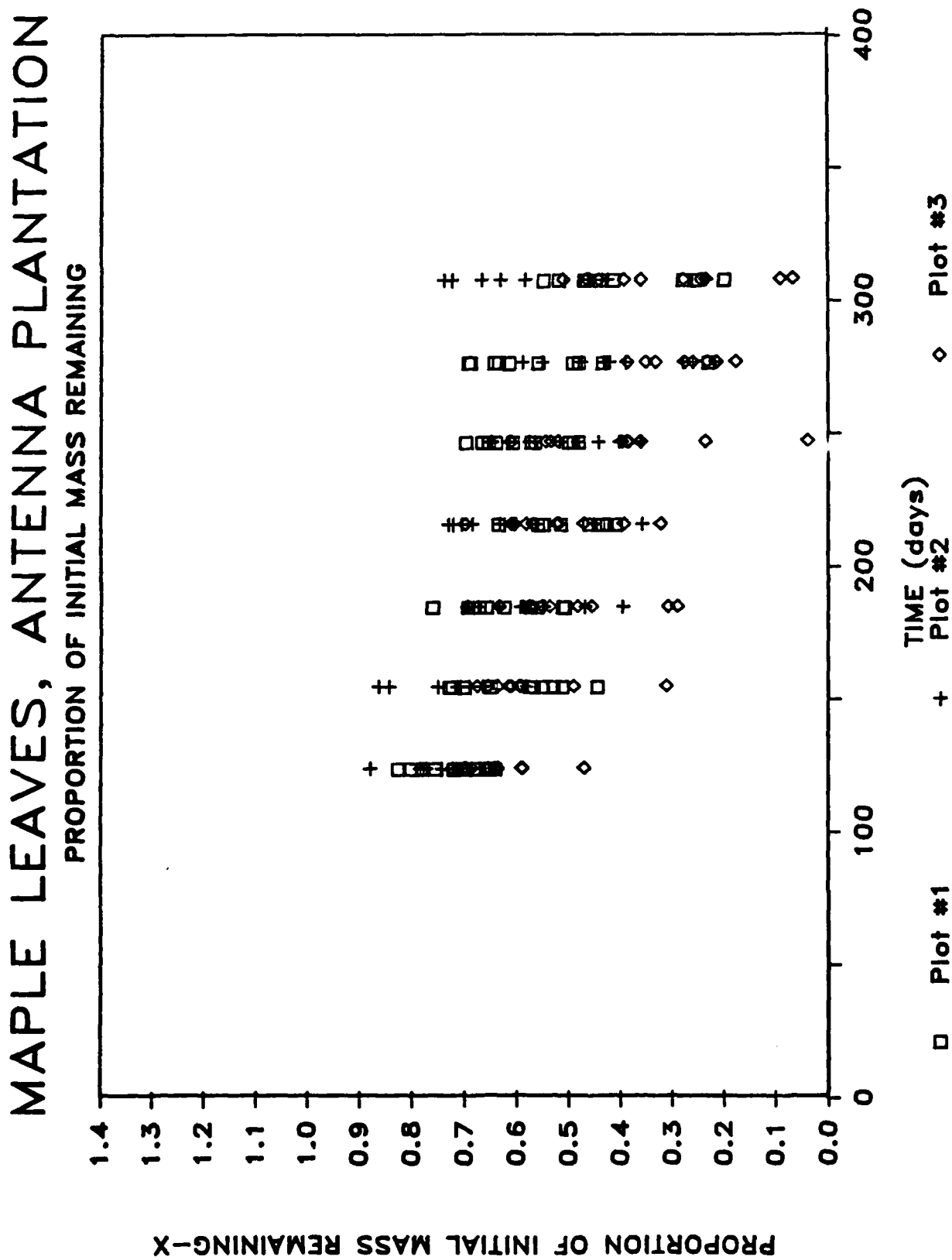


Figure 28.

# MAPLE LEAVES, ANTENNA POLE-STAND PROPORTION OF INITIAL MASS REMAINING

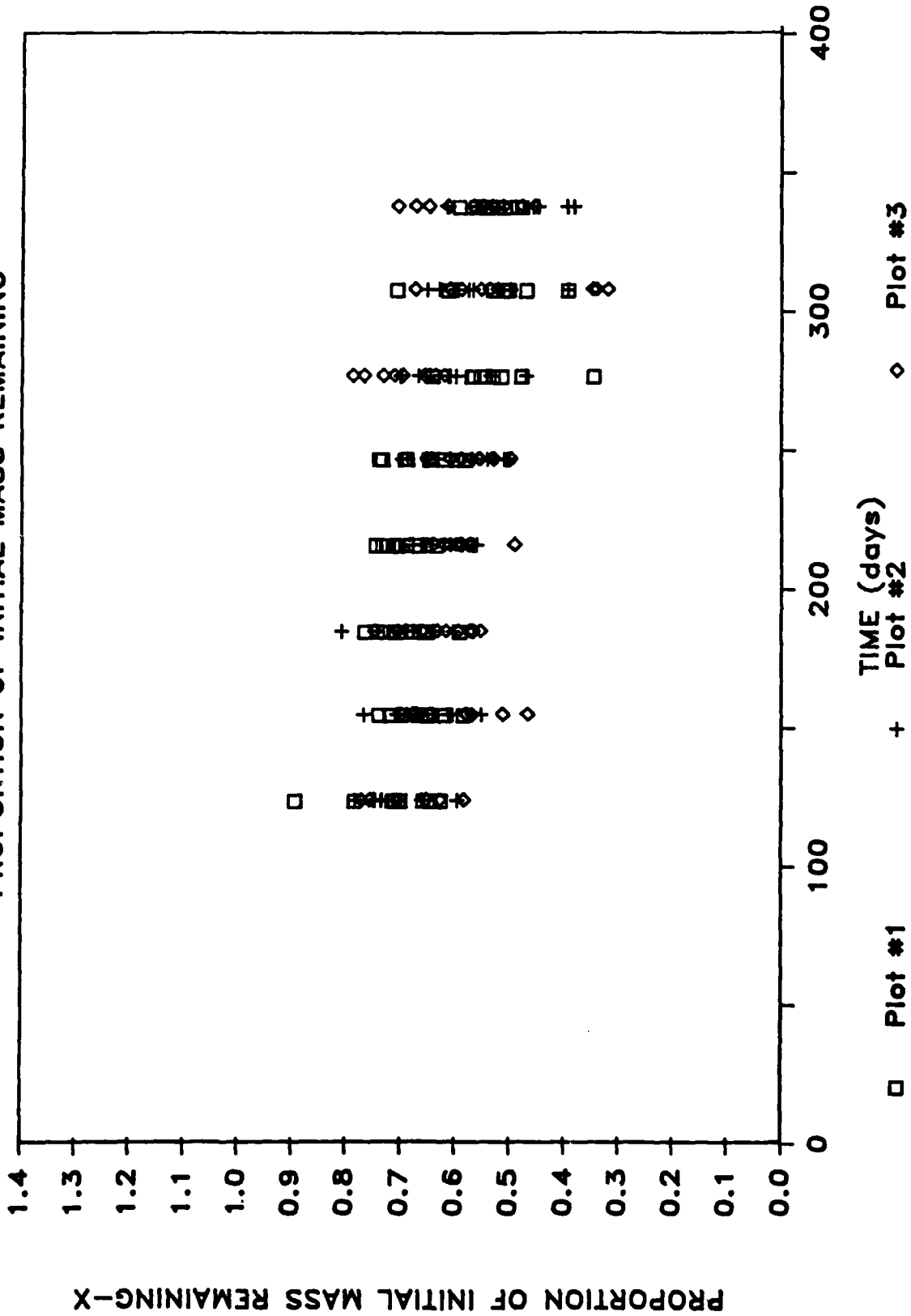


Figure 29.

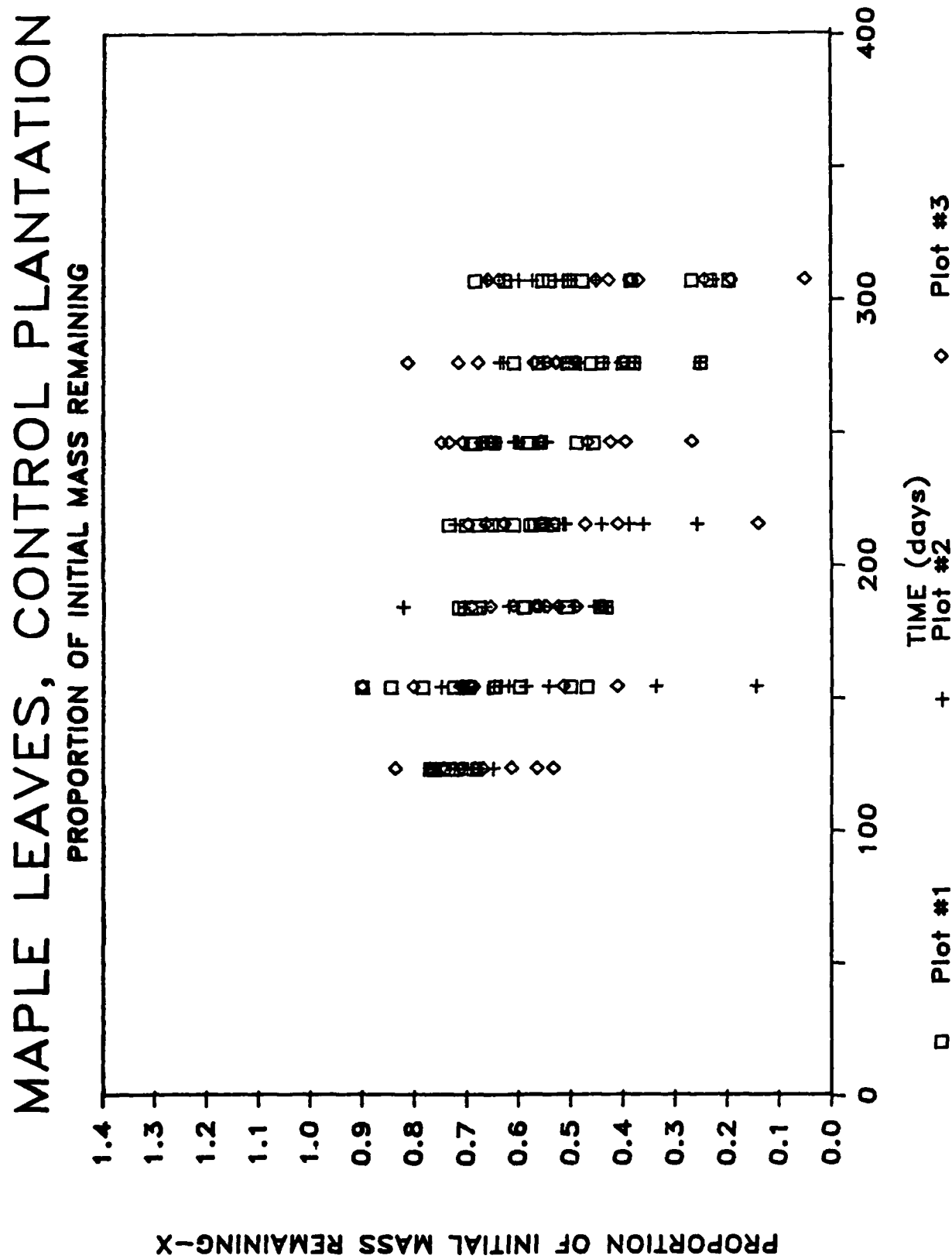


Figure 30.

# MAPLE LEAVES, CONTROL POLE-STAND

PROPORTION OF INITIAL MASS REMAINING

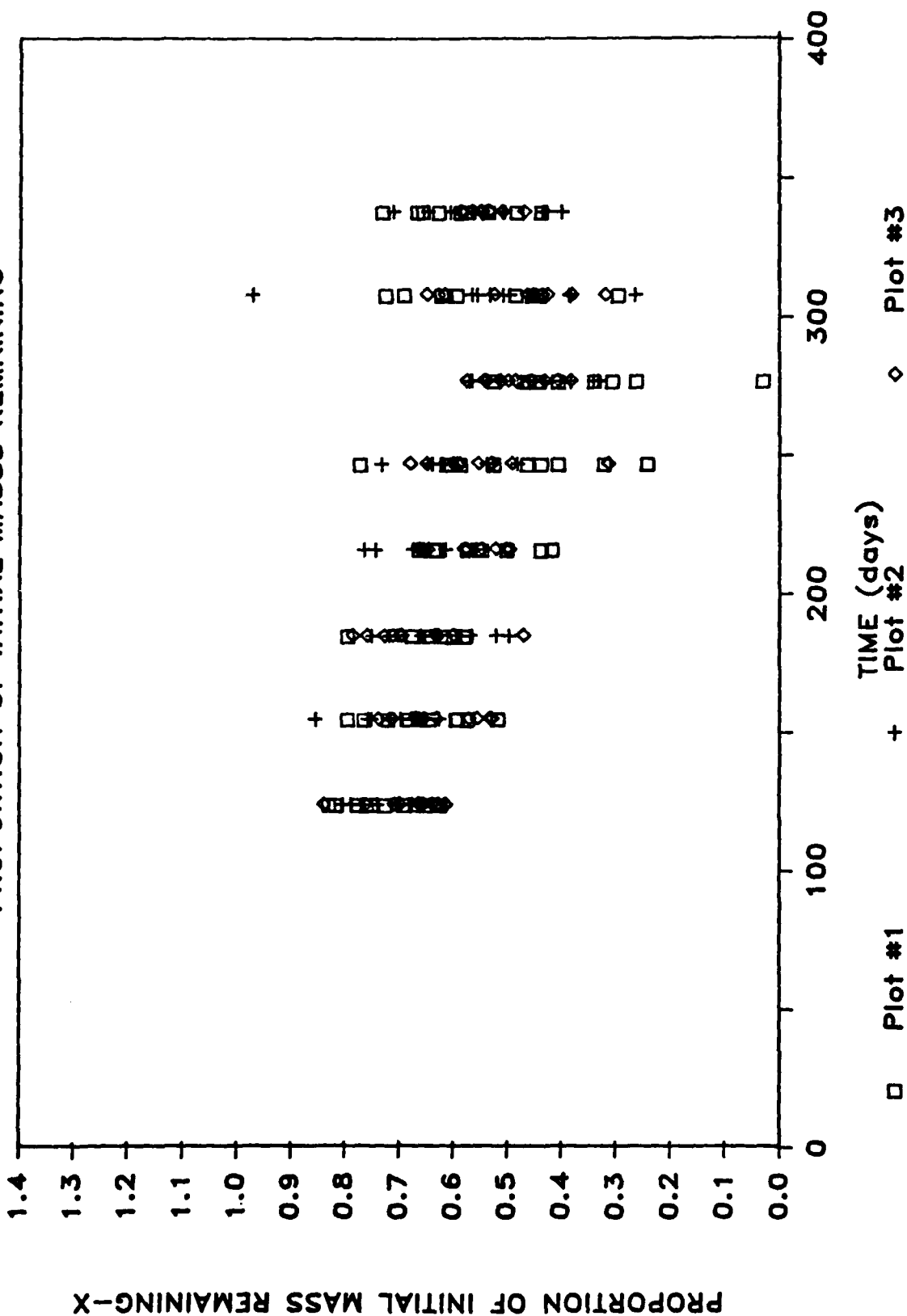
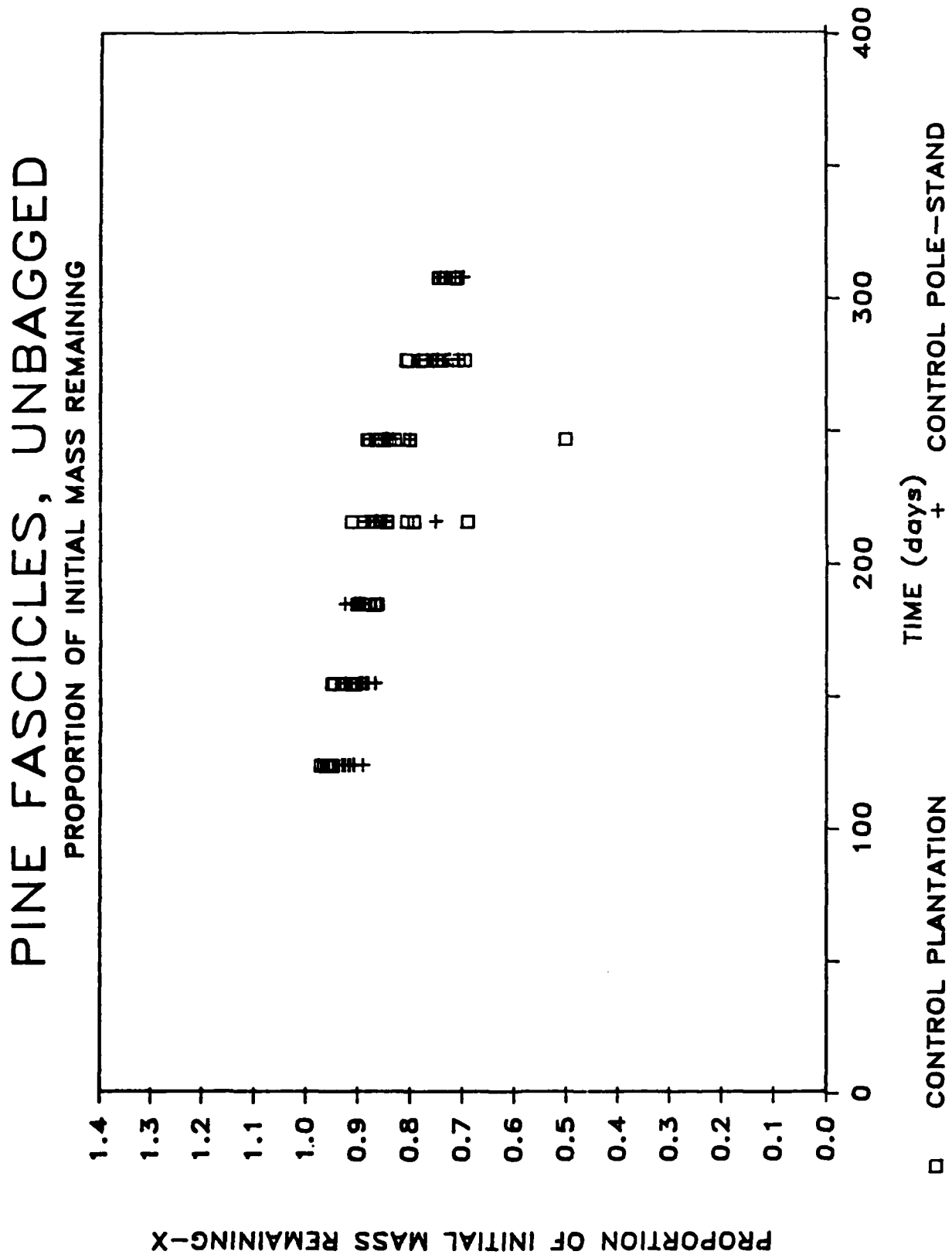
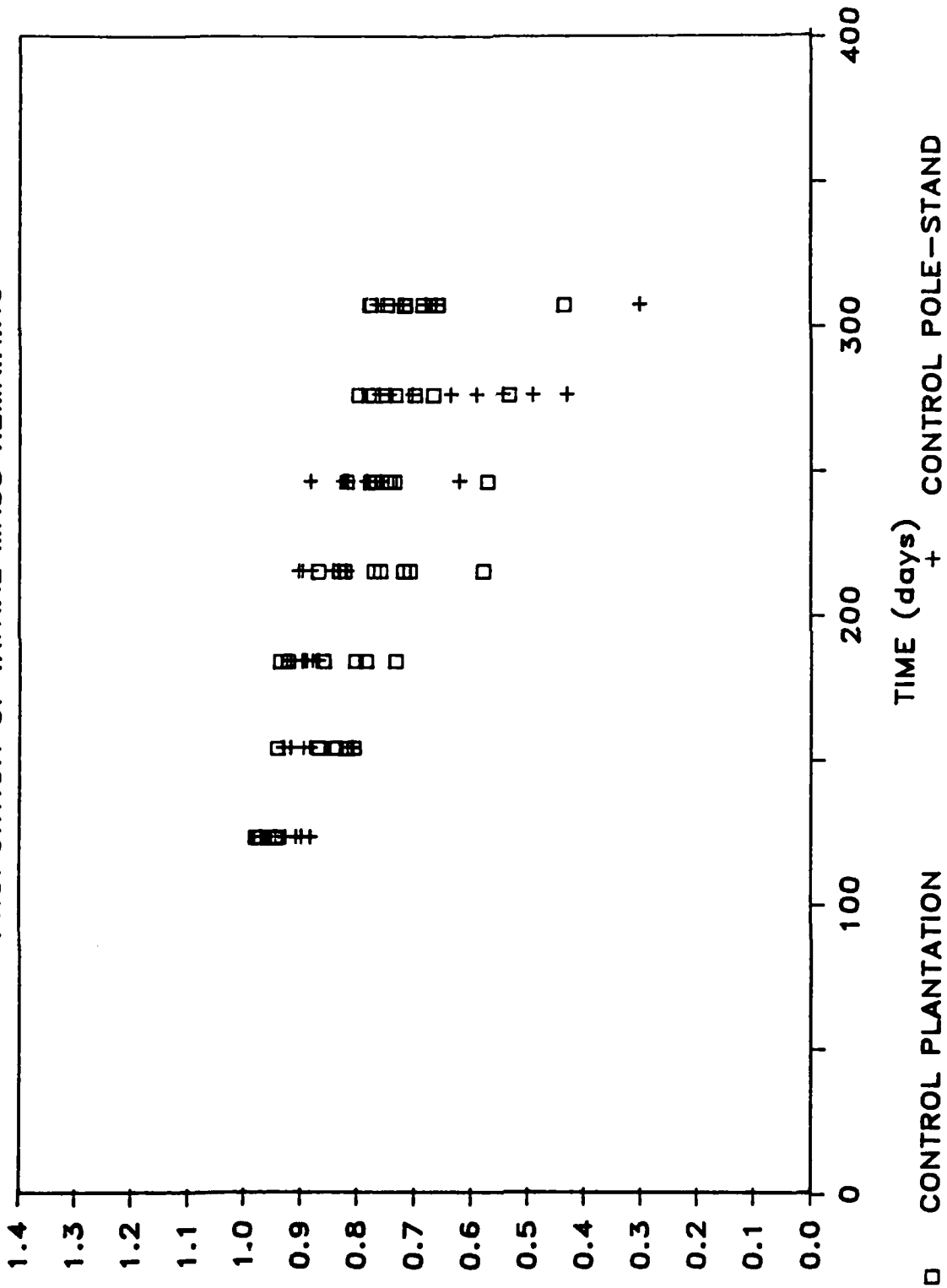


Figure 31.



PROPORTION OF INITIAL MASS REMAINING-X



mass than had their counterpart bulk maple samples ( $\alpha = .05$ ). Similarly, individual, bagged and unbagged pine fascicles and unbagged oak leaves had lost less mass than had individual bagged oak leaves, while maple leaves decomposed fastest of all ( $\alpha = .05$ ). No significant differences were detected in the rates at which individual, bagged pine fascicles and oak leaves decomposed at the different study locations. On the other hand, individual, bagged maple leaves decomposed fastest in the Antenna pole-stand ( $\alpha = .05$ ). Using the data from the 2 November retrievals, no significant difference was detected in the rate of unbagged pine fascicle or oak leaf decomposition between the Control site plantation and pole-stand. Analysis of bulk mass loss for each species (composited over all study locations) over the course of the 1984-85 field season showed that most monthly intervals resulted in significant mass loss ( $\alpha = .05$ ) until September (for maple) or October (for pine and oak).

One of the striking differences between the behavior of the three litter species was the greater variability which built up over time within the maple samples as opposed to the oak samples and, especially, the pine samples. This variability was more noticeable within the tethered fascicle/leaf samples than in the bulk samples, and in the plantations rather than in the pole-stands. One likely explanation is the fact that litterfall began to shelter pole-stand samples from environmental extremes fairly early in the season. This sheltering effect increases markedly with the onset of major leaf-fall in September (Figures 8.1 and 8.2, pp. 174-175, from the Annual Report 1985 of the Herbaceous Plant Cover and Tree Studies project). The differences in variability between species fit the hypotheses that pine fascicles decompose more uniformly, and somewhat more slowly, than do oak or maple leaves, and that maple leaves decompose least uniformly and most rapidly of the three species. Fragmentation among the tethered maple leaves was much more severe than among the oak leaves. One reason for the apparently greater uniformity of pine fascicle decomposition was the fact that the influence of fragmentation was eliminated for pine by discarding broken fascicles



upon retrieval from the field. Nevertheless, fragmentation was much less severe among the tethered oak leaves than among their maple counterparts. Compared to maple leaves, fragmentation among the oak leaves was due less to their fragile nature and more to the development of localized areas of extreme decomposition. Within tethered oak leaf envelopes, great variability was noted in the relative rates at which individual leaves decomposed. A table of within-envelope and location-wide standard deviations will soon be available for each species. This analysis will help to determine whether or not individual leaves within an envelope contribute meaningfully to sample size. We have considered this to be the case. A more labor-intensive alternative sampling design is being considered for incorporation into the 1986-87 study. This alternative design would require approximately three times as many envelopes, each containing one leaf representing each species. In this way, individual leaves representing each species would constitute undeniably independent samples.

In light of our experience in 1985, there seems to be little value to be gained from trying to estimate fragmentation rates for oak and maple. In the first place, we have no information on the decomposition status of the specific fragments evolved; in the second place, maple leaves are retrieved in such poor condition as to defy surface area determination.

Considering the variability in decomposition rate observed among both oak and maple leaves, the relationships between mass loss and leaf surface area (one side) and leaf density (mass per unit surface area) were investigated. Tables 7 and 8 present Pearson's product moment correlation coefficients for individual leaf mass loss with leaf surface area and density by study location, for oak and maple, respectively. This analysis was intended to determine whether the observed variability in mass loss was due to differences between shade leaves (generally larger and thinner) and sun leaves (generally smaller and thicker). No useful relationship was detected. During the 1985-86 study, greater attention is being placed on the position

Table 7. Means and standard deviations among tethered oak leaves retrieved 2 November, 1985, for X, individual leaf area, and initial individual leaf density, and Pearson's product moment correlation coefficients for X with leaf area and leaf density.

	Bagged Leaves					Unbagged Leaves	
Location <sup>a</sup>	11	21	22	31	32	31	32
Sample Size	30	30	30	30	30	8	8
Mean X <sup>b</sup>	0.5998	0.6307	0.6482	0.6465	0.6785	0.6887	0.6610
S.D.X	0.1095	0.1723	0.0618	0.1117	0.0858	0.1106	0.1499
Mean Area <sup>c</sup>	48.1897	41.8637	39.7753	39.3043	42.1603	41.4437	37.2388
S.D.Area	17.5747	21.3628	19.5781	14.4834	20.0382	16.0026	35.9271
Mean Dens <sup>d</sup>	0.0073	0.0067	0.0073	0.0075	0.0075	0.0083	0.0073
S.D.Dens	0.0011	0.0012	0.0013	0.0010	0.0012	0.0013	0.0009
rX.Area	-0.1292	-0.2274	-0.2117	-0.1308	0.1672	-0.5828	0.1761
rX.Dens	0.2231	0.2544	0.4868*	0.3851*	0.2658	0.1305	-0.0199
r <sub>28</sub> , .05 <sup>e</sup>	0.3609	0.3609	0.3609	0.3609	0.3609	0.7067	0.7067

a/ 11 = Ground site plantation; 21 = Antenna site plantation; 22 = Antenna site pole-stand; 31 = Control site plantation; 32 = Control site pole-stand.

b/ X = proportion of original weight remaining on 2 Nov., 1985, after 305 days in the field (30°C basis)

c/ mean of the three area determinations, in cm<sup>2</sup>

d/ result of dividing initial mass (30°C basis) by initial leaf area (cm<sup>2</sup>)

e/  $r_{test} = (t_{.05^2} / (t_{.05^2} + n - 2)) \%$

f/ \* correlation is significant ( $\alpha = .05$ )

Table 8. Means and standard deviations among tethered maple leaves retrieved 2 November, 1985, for X, individual leaf area, and initial individual leaf density, and Pearson's product moment correlation coefficients for X with leaf area and leaf density.

Location <sup>a</sup>	Bagged Leaves			Unbagged Leaves	
	11	21	22	31	32
Sample Size	30	30	29	29	30
Mean X <sup>b</sup>	0.3763	0.4091	0.5297	0.4415	0.5122
S.D.X	0.1488	0.1709	0.0969	0.1655	0.1437
Mean Area <sup>c</sup>	33.1990	32.5590	34.1220	34.0603	27.8160
S.D.Area	11.9014	12.0297	12.9408	14.0778	11.1824
Mean Dens <sup>d</sup>	0.0068	0.0073	0.0061	0.0061	0.0059
S.D.Dens	0.0018	0.0014	0.0012	0.0015	0.0011
rX.Area	0.1318	0.0871	0.0599	0.0448	0.0632
rX.Dens	-0.2748	0.0983	0.3003	0.3080	0.1070
r <sub>28</sub> , .05 <sup>e</sup>	0.3609	0.3609	0.3609	0.3673	0.3609

a/ 11 = Ground site plantation; 21 = Antenna site plantation; 22 = Antenna site pole-stand; 31 = Control stand plantation; 32 = Control stand pole-stand.

b/ X = proportion of original weight remaining on Nov., after 3 days in the field (30°C basis)

c/ mean of the three area determinations, in cm<sup>2</sup>

d/ result of dividing initial mass (30°C basis) by initial leaf area (cm<sup>2</sup>)

e/ rtest = (t<sub>.05</sub><sup>2</sup>/(t<sub>.05</sub><sup>2</sup>+n-2))%

of tethered individual oak and maple leaves in their envelopes. The uppermost leaf in each oak envelope on the ground is being noted at the time of retrieval. We suspect that leaf position in the envelopes, especially in the plantations, may be responsible for much of the variation in mass loss between leaves in the same envelope. For the 1985-86 study, one maple leaf was sewn into each quarter of each envelope. This eliminates the problem of broken petioles and helps to maintain leaf integrity.

The patterns of total mass loss development over time at the five study locations have been evaluated by fitting single exponential non-linear regression models, with and without lag periods, to the data collected at each location for each type of litter sample employed with each litter species. Characteristics of the models without lag periods are presented in Tables 9 through 11, for pine, oak, and maple, respectively. Characteristics of the models with lag periods are presented in Tables 12 through 14, for pine, oak, and maple, respectively. The models without lag periods are also presented graphically in Figures 33 through 44.

For the purpose of review, before discussing the 1985 data, the following comments were made in the 1984 Annual Report concerning our attempts to apply exponential models to the mass loss data from the 1983-84 study. Three variations of the single exponential model were evaluated in 1984. Table 8 and Figures 29-34, from Annual Report 1984 for the Litter Decomposition and Microflora project, are reproduced as Appendix A to this report. The simplest form did not account for the first five winter months of slow decomposition with a lag period (Figures 29 and 30). The second and third forms of single exponential model both incorporated a lag period. The second form (Figures 31 and 32) selected independent lag factors for each location and method, while the third form (Figures 33 and 34) forced a lag period of 89 days (the mean lag period derived for the bulk and individual fascicle equations at the three locations). Lag periods varied in length, from 85 to 95 days following December 1, 1984, dispersal. Confidence intervals based on t-tests were calculated in

Table 9. Characteristics of single exponential models<sup>a</sup> fitted to first year total mass loss from fresh-fallen red pine foliar litter at the overhead, ground, and control sites.

	Antenna Site				Ground Site	
	Plantation		Pole-Stand		Plantation	
	Tethered Bagged <sup>b</sup>	Bulk Samples <sup>c</sup>	Tethered Bagged	Bulk Samples	Tethered Bagged	Bulk Samples
$X = e^{-kt}$ ; $k_i = 7.50 \times 10^{-4}$						
$k$ ( $\times 10^{-4}$ )	7.08	8.63	7.85	9.30	7.62	9.68
$SD_k$ ( $\times 10^{-5}$ ) <sup>d</sup>	1.7	2.7	1.2	2.3	1.7	2.6
$df^e$	174	41	230	47	173	41
$CI_k$ upper ( $\times 10^{-4}$ ) <sup>f</sup>	7.41	9.18	8.09	9.76	7.95	10.21
$CI_k$ lower ( $\times 10^{-4}$ )	6.75	8.08	7.61	8.84	7.29	9.15
$\Sigma$ residuals <sup>g</sup>	0.382	0.049	0.338	0.049	0.376	0.044

a/ Models were derived using BMDPAR, for derivative-free nonlinear regression. Mass loss is expressed as the proportion (X) of initial mass remaining at time of sampling (t); k is the decomposition rate constant ( $k_i$  is the estimate of k used to initiate the iterative process). Samples were retrieved monthly from mid-May through early December.

b/ Tethered bagged samples consist of sets of 10 individually identified and pre-weighed, perfectly-formed fascicles bagged in nylon envelopes (9 in x 6 in, 3 mm mesh).

c/ Bulk samples consist of 10 g of bagged (12 in x 8 in, 3 mm mesh, nylon envelopes) pine fascicles.

d/ asymptotic standard deviation

e/ degrees of freedom

f/ upper and lower bounds of confidence interval ( $\alpha = 0.05$ )

g/ Tethered unbagged samples were prepared as described in b/, but were staked to the forest floor unbagged.

Table 9. (cont)

	Control Site					
	Plantation			Pole-Stand		
	Tethered Bagged <sup>b</sup>	Tethered Unbagged <sup>b</sup>	Bulk Samples <sup>c</sup>	Tethered Bagged	Tethered Unbagged	Bulk Samples
$X = e^{-kt}$ ; $k_i = 7.50 \times 10^{-4}$						
$k$ ( $\times 10^{-4}$ )	7.79	7.26	9.12	9.54	7.14	9.74
$SD_k$ ( $\times 10^{-5}$ ) <sup>d</sup>	1.9	3.9	2.3	1.2	2.6	1.5
$df^e$	170	65	41	233	60	44
$CI_k$ upper ( $\times 10^{-4}$ ) <sup>f</sup>	8.16	8.04	9.58	9.78	7.66	10.04
$CI_k$ lower ( $\times 10^{-4}$ )	7.42	6.48	8.66	9.30	6.62	9.44
$\Sigma$ residuals <sup>g</sup>	0.406	0.281	0.034	0.314	0.099	0.018

Table 10. Characteristics of single exponential models<sup>a</sup> fitted to first year total mass loss from fresh-fallen northern red oak foliar litter at the overhead, ground, and control sites.

	Antenna Site				Ground Site	
	Plantation		Pole-Stand		Plantation	
	Tethered Bagged <sup>b</sup>	Bulk Samples <sup>c</sup>	Tethered Bagged	Bulk Samples	Tethered Bagged	Bulk Samples
$X = e^{-kt}$ ; $k_i = 7.50 \times 10^{-4}$						
$k$ ( $\times 10^{-4}$ )	10.58	8.78	9.10	8.13	11.86	9.82
$SD_k$ ( $\times 10^{-5}$ ) <sup>d</sup>	4.4	4.0	2.5	4.2	3.8	3.7
$df^e$	200	41	230	47	200	41
$CI_k$ upper ( $\times 10^{-4}$ ) <sup>f</sup>	11.44	9.59	9.59	8.98	12.60	10.57
$CI_k$ lower ( $\times 10^{-4}$ )	9.72	7.97	8.61	7.28	11.12	9.07
$I$ residuals <sup>g</sup>	2.824	0.107	1.456	0.175	2.003	0.087

a/ Models were derived using BMDP4R, for derivative-free nonlinear regression. Mass loss is expressed as the proportion ( $X$ ) of initial mass remaining at time of sampling ( $t$ );  $k$  is the decomposition rate constant ( $k_i$  is the estimate of  $k$  used to initiate the iterative process). Samples were retrieved monthly from mid-May through early December.

b/ Tethered bagged samples consist of sets of 8 - 10 individually identified and pre-weighed, leaves, in nearly perfect condition, bagged in nylon mesh envelopes (9 in x 6 in, 3 mm mesh).

c/ Bulk samples consist of 12 g of bagged (12 in x 8 in, 3 mm mesh, nylon envelopes) oak leaves.

d/ asymptotic standard deviation

e/ degrees of freedom

f/ upper and lower bounds of confidence interval ( $\alpha = 0.05$ )

g/ Tethered unbagged samples were prepared as described in b/, but were staked to the forest floor unbagged.

Table 10. (cont)

	Control Site					
	Plantation			Pole-Stand		
	Tethered Bagged <sup>b</sup>	Tethered Unbagged <sup>b</sup>	Bulk Samples <sup>c</sup>	Tethered Bagged	Tethered Unbagged	Bulk Samples
$X = e^{-kt}$ ; $k_i = 7.50 \times 10^{-4}$						
$k$ ( $\times 10^{-4}$ )	10.28	10.00	8.43	9.41	9.71	9.40
$SD_k$ ( $\times 10^{-5}$ ) <sup>d</sup>	3.5	6.1	5.0	2.6	7.6	4.6
$df^e$	200	51	41	230	52	47
$CI_k$ upper ( $\times 10^{-4}$ ) <sup>f</sup>	10.97	11.23	9.44	9.92	11.24	10.33
$CI_k$ lower ( $\times 10^{-4}$ )	9.59	8.77	7.42	8.90	8.18	8.47
$I$ residuals <sup>g</sup>	1.837	0.379	0.174	1.582	0.604	0.199

Table 11. Characteristics of single exponential models<sup>a</sup> fitted to first year total mass loss from fresh-fallen red maple foliar litter at the overhead, ground, and control sites.

	Antenna Site				Ground Site	
	Plantation		Pole-Stand		Plantation	
	Tethered Bagged <sup>b</sup>	Bulk Samples <sup>c</sup>	Tethered Bagged	Bulk Samples	Tethered Bagged	Bulk Samples

$$X = e^{-kt} ; k_i = 7.50 \times 10^{-4}$$

k (x10 <sup>-4</sup> )	25.94	24.29	18.63	19.20	29.82	28.62
SD <sub>k</sub> (x 10 <sup>-5</sup> ) <sup>d</sup>	7.1	6.0	3.5	4.3	8.2	6.9
df <sup>e</sup>	207	41	233	47	208	41
CI <sub>k</sub> upper (x 10 <sup>-4</sup> ) <sup>f</sup>	27.33	25.50	19.32	20.07	31.43	30.01
CI <sub>k</sub> lower (x 10 <sup>-4</sup> )	24.55	23.08	17.94	18.33	28.21	27.23
I residuals <sup>g</sup>	3.444	0.106	1.629	0.101	3.818	0.115

a/ Models were derived using BMDPAR, for derivative-free nonlinear regression. Mass loss is expressed as the proportion (X) of initial mass remaining at time of sampling (t); k is the decomposition rate constant (k<sub>i</sub> is the estimate of k used to initiate the iterative process). Samples were retrieved monthly from mid-May through early December.

b/ Tethered bagged samples consist of sets of 10 individually identified and pre-weighed leaves, in nearly perfect condition, bagged in nylon mesh envelopes (9 in x 6 in, 3 mm mesh).

c/ Bulk samples consist of 12 g of bagged (12 in x 8 in, 3 mm mesh, nylon envelopes) maple leaves.

d/ asymptotic standard deviation

e/ degrees of freedom

f/ upper and lower bounds of confidence interval (α = 0.05)

g/ Due to the extremely fragile nature of maple foliage, tethered unbagged sets of leaves were not studied.

Table 11. (cont)

	Control Site					
	Plantation			Pole-Stand		
	Tethered Bagged <sup>b</sup>	Tethered Unbagged <sup>g</sup>	Bulk Samples <sup>c</sup>	Tethered Bagged	Tethered Unbagged	Bulk Samples

$$X = e^{-kt} ; k_i = 7.50 \times 10^{-4}$$

k (x10 <sup>-4</sup> )	23.03	N.A.	23.57	21.08	N.A.	20.26
SD <sub>k</sub> (x 10 <sup>-5</sup> ) <sup>d</sup>	6.5	N.A.	6.5	4.7	N.A.	2.8
df <sup>e</sup>	209	0	41	239	0	46
CI <sub>k</sub> upper (x 10 <sup>-4</sup> ) <sup>f</sup>	24.30	N.A.	24.88	22.00	N.A.	20.82
CI <sub>k</sub> lower (x 10 <sup>-4</sup> )	21.76	N.A.	22.26	20.16	N.A.	19.70
I residuals <sup>g</sup>	3.401	N.A.	0.131	2.758	N.A.	0.039

Table 12. Characteristics of single exponential models with lag periods<sup>a</sup> fitted to first year total mass loss from fresh-fallen red pine foliar litter at the overhead, ground, and control sites.

	Antenna Site				Ground Site	
	Plantation		Pole-Stand		Plantation	
	Tethered Bagged <sup>b</sup>	Bulk Samples <sup>c</sup>	Tethered Bagged	Bulk Samples	Tethered Bagged	Bulk Samples
	$X = e^{-k(t-l)} ; k_i = 7.50 \times 10^{-4}, l_i = 89$					
k ( $\times 10^{-4}$ )	13.29	13.67	11.00	11.03	13.41	13.34
SD <sub>k</sub> ( $\times 10^{-5}$ ) <sup>d</sup>	4.7	6.6	3.8	8.0	4.9	8.3
l	115	93	77	42	108	69
SD <sub>l</sub>	4.5	7.4	6.3	15.7	5.0	11.0
df <sup>e</sup>	173	40	229	46	172	40
CI <sub>k</sub> upper ( $\times 10^{-4}$ ) <sup>f</sup>	14.21	15.00	11.74	12.64	14.37	15.02
CI <sub>k</sub> lower ( $\times 10^{-4}$ )	12.37	12.34	10.26	9.42	12.45	11.66
CI <sub>l</sub> upper	123.82	107.96	89.35	73.64	117.8	91.23
CI <sub>l</sub> lower	106.18	78.04	64.65	10.36	98.2	46.77
I residuals <sup>g</sup>	0.183	0.019	0.254	0.044	0.199	0.029

a/ Models were derived using BMDPAR, for derivative-free nonlinear regression. Mass loss is expressed as the proportion (X) of initial mass remaining at time of sampling (t); k is the decomposition rate constant ( $k_i$  is the estimate of k used to initiate the iterative process); l is the lag period in days. Samples were retrieved monthly from mid-May through early December.

b/ Tethered bagged samples consist of sets of 10 individually identified and pre-weighed, perfectly-formed fascicles bagged in nylon envelopes (9 in x 6 in, 3 mm mesh).

c/ Bulk samples consist of 10 g of bagged (12 in x 8 in, 3 mm mesh, nylon envelopes) pine fascicles.

d/ asymptotic standard deviation

e/ degrees of freedom

f/ upper and lower bounds of confidence interval ( $\alpha = 0.05$ )

g/ Tethered unbagged samples were prepared as described in b/, but were staked to the forest floor unbagged.

Table 12. (cont)

	Control Site					
	Plantation			Pole-Stand		
	Tethered Bagged <sup>b</sup>	Tethered Unbagged <sup>g</sup>	Bulk Samples <sup>c</sup>	Tethered Bagged	Tethered Unbagged	Bulk Samples
	$X = e^{-k(t-l)} ; k_i = 7.50 \times 10^{-4}, l_i = 89$					
k ( $\times 10^{-4}$ )	13.04	14.73	12.03	11.97	11.90	11.49
SD <sub>k</sub> ( $\times 10^{-5}$ ) <sup>d</sup>	5.8	12.2	7.5	4.0	8.3	4.8
l	100	127	61	55	97	41
SD <sub>l</sub>	6.3	10.0	11.6	6.8	9.8	9.1
df <sup>e</sup>	169	64	40	232	59	43
CI <sub>k</sub> upper ( $\times 10^{-4}$ ) <sup>f</sup>	14.18	17.17	13.55	12.75	13.56	12.46
CI <sub>k</sub> lower ( $\times 10^{-4}$ )	11.90	12.29	10.51	11.19	10.24	10.52
CI <sub>l</sub> upper	112.35	147.00	84.44	68.33	116.61	59.36
CI <sub>l</sub> lower	87.65	107.00	37.56	41.67	77.39	22.64
I residuals <sup>g</sup>	0.264	0.172	0.024	0.267	0.061	0.014



Table 13. Characteristics of single exponential models with lag periods<sup>a</sup> fitted to first year total mass loss from fresh-fallen northern red oak foliar litter at the overhead, ground, and control sites.

	Antenna Site				Ground Site	
	Plantation		Pole-Stand		Plantation	
	Tethered Bagged <sup>b</sup>	Bulk Samples <sup>c</sup>	Tethered Bagged	Bulk Samples	Tethered Bagged	Bulk Samples
	$X = e^{-k(t-l)} ; k_i = 7.50 \times 10^{-4}, l_i = 89$					
$k (x 10^{-4})$	20.19	13.97	14.90	13.43	21.72	16.91
$SD_k (x 10^{-5})^d$	15.7	13.2	8.4	13.0	13.2	8.6
$l$	121	94	106	107	115	106
$SD_l$	9.9	14.4	8.9	15.0	7.9	7.1
$df^e$	199	40	229	46	199	40
$CI_k$ upper $(x 10^{-4})^f$	23.27	16.64	16.55	16.05	24.31	18.65
$CI_k$ lower $(x 10^{-4})^f$	17.11	11.30	13.25	10.81	19.13	15.17
$CI_l$ upper	140.40	123.10	123.44	137.22	130.48	120.35
$CI_l$ lower	101.60	64.90	88.56	76.78	99.52	91.65
$\Sigma$ residuals <sup>g</sup>	2.339	0.075	1.183	0.124	1.531	0.031

a/ Models were derived using BMDP4R, for derivative-free nonlinear regression. Mass loss is expressed as the proportion (X) of initial mass remaining at time of sampling (t); k is the decomposition rate constant ( $k_i$  is the estimate of k used to initiate the iterative process); l is the lag period in days. Samples were retrieved monthly from mid-May through early December.

b/ Tethered bagged samples consist of sets of 10 individually identified and pre-weighed, perfectly-formed fascicles bagged in nylon envelopes (9 in x 6 in, 3 mm mesh).

c/ Bulk samples consist of 10 g of bagged (12 in x 8 in, 3 mm mesh, nylon envelopes) pine fascicles.

d/ asymptotic standard deviation

e/ degrees of freedom

f/ upper and lower bounds of confidence interval ( $\alpha = 0.05$ )

g/ Tethered unbagged samples were prepared as described in b/, but were staked to the forest floor unbagged.

Table 13. (cont)

	Control Site					
	Plantation			Pole-Stand		
	Tethered Bagged <sup>b</sup>	Tethered Unbagged <sup>b</sup>	Bulk Samples <sup>c</sup>	Tethered Bagged	Tethered Unbagged	Bulk Samples
	$X = e^{-k(t-l)} ; k_i = 7.50 \times 10^{-4}, l_i = 89$					
$k (x 10^{-4})$	20.18	17.15	15.47	17.10	20.60	18.50
$SD_k (x 10^{-5})^d$	11.7	22.6	16.1	8.2	25.4	9.2
$l$	124	107	115	122	135	132
$SD_l$	7.2	18.9	13.8	6.8	14.1	6.4
$df^e$	199	50	40	229	51	46
$CI_k$ upper $(x 10^{-4})^f$	22.47	21.69	18.72	18.71	25.70	20.35
$CI_k$ lower $(x 10^{-4})^f$	17.89	12.61	12.22	15.49	15.50	16.65
$CI_l$ upper	138.11	144.99	142.89	135.33	163.33	144.90
$CI_l$ lower	103.89	69.01	87.11	108.67	106.67	119.10
$\Sigma$ residuals <sup>g</sup>	1.322	0.314	0.115	1.110	0.430	0.059

Table 14. Characteristics of single exponential models with lag periods<sup>a</sup> fitted to first year total mass loss from fresh-fallen red maple foliar litter at the overhead, ground, and control sites.

	Antenna Site				Ground Site	
	Plantation		Pole-Stand		Plantation	
	Tethered Bagged <sup>b</sup>	Bulk Samples <sup>c</sup>	Tethered Bagged	Bulk Samples	Tethered Bagged	Bulk Samples
	$X = e^{-k(t-l)} ; k_i = 7.50 \times 10^{-4}, l_i = 89$					
$k (x 10^{-4})$	29.96	22.90	12.24	14.21	37.22	26.64
$SD_k (x 10^{-5})^d$	27.2	23.0	12.0	13.7	31.3	26.5
$l$	32	-15	-138	-92	47	-18
$SD_l$	18.0	25.0	38.4	33.2	15.0	24.7
$df^e$	206	40	232	46	207	40
$CI_k$ upper $(x 10^{-4})^f$	35.29	27.55	14.59	16.97	43.35	32.00
$CI_k$ lower $(x 10^{-4})$	24.63	18.25	9.89	11.45	31.09	21.28
$CI_l$ upper	67.28	35.52	-62.70	-25.10	76.40	31.92
$CI_l$ lower	-3.28	-65.52	-213.30	-158.90	17.60	-67.92
$I$ residuals <sup>g</sup>	3.404	0.105	1.437	0.077	3.708	0.113

a/ Models were derived using BMDP4R, for derivative-free nonlinear regression. Mass loss is expressed as the proportion ( $X$ ) of initial mass remaining at time of sampling ( $t$ );  $k$  is the decomposition rate constant ( $k_i$  is the estimate of  $k$  used to initiate the iterative process);  $l$  is the lag period in days. Samples were retrieved monthly from mid-May through early December.

b/ Tethered bagged samples consist of sets of 10 individually identified and pre-weighed, perfectly-formed fascicles bagged in nylon envelopes (9 in x 6 in, 3 mm mesh).

c/ Bulk samples consist of 10 g of bagged (12 in x 8 in, 3 mm mesh, nylon envelopes) pine fascicles.

d/ asymptotic standard deviation

e/ degrees of freedom

f/ upper and lower bounds of confidence interval ( $\alpha = 0.05$ )

g/ Tethered unbagged samples were prepared as described in b/, but were staked to the forest floor unbagged.

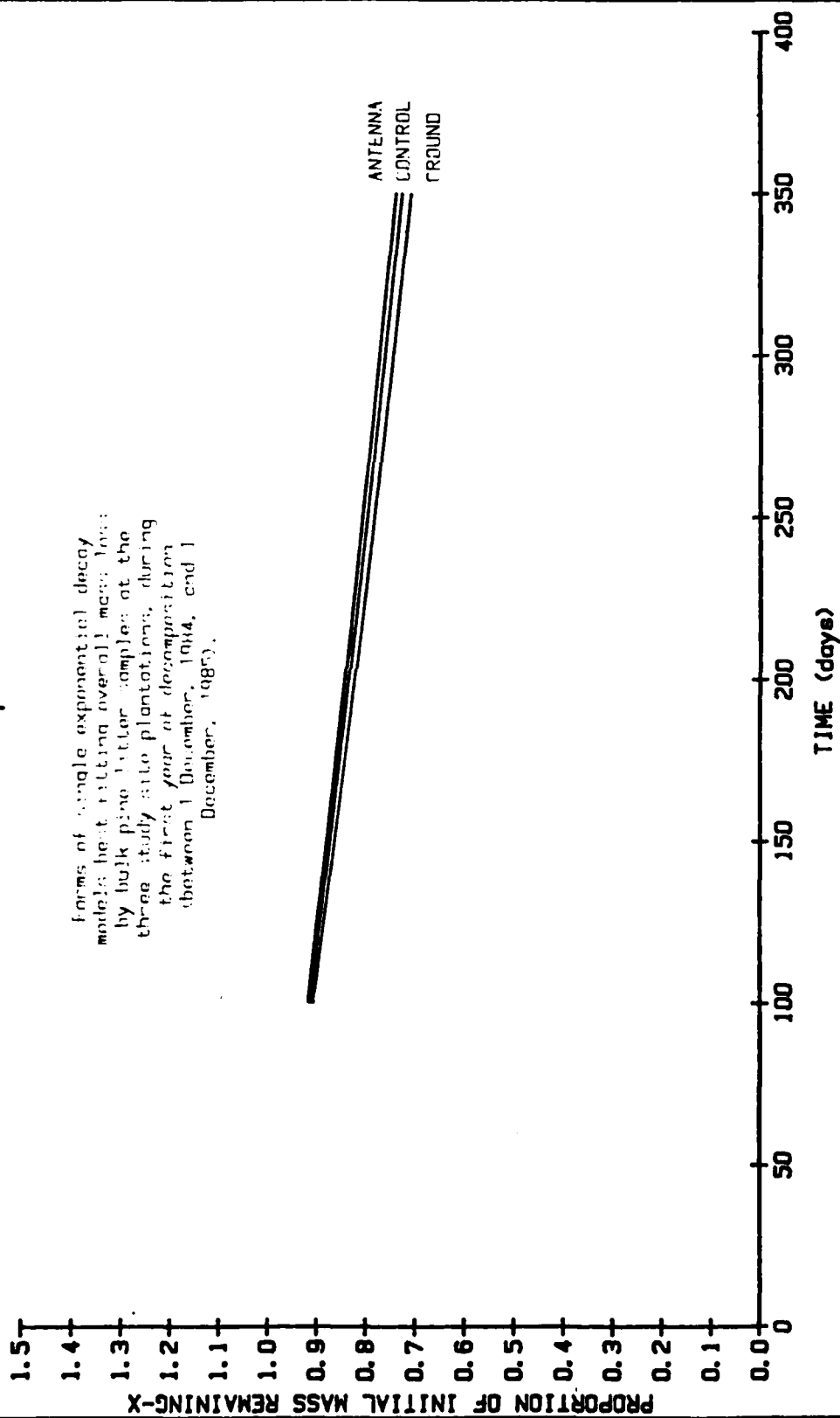
Table 14. (cont)

	Control Site					
	Plantation			Pole-Stand		
	Tethered Bagged <sup>b</sup>	Tethered Unbagged <sup>g</sup>	Bulk Samples <sup>c</sup>	Tethered Bagged	Tethered Unbagged	Bulk Samples
	$X = e^{-k(t-l)} ; k_i = 7.50 \times 10^{-4}, l_i = 89$					
$k (x 10^{-4})$	21.21	N.A.	18.38	17.61	N.A.	17.53
$SD_k (x 10^{-5})^d$	24.8	N.A.	23.7	16.7	N.A.	9.5
$l$	-21	N.A.	-69	-51	N.A.	-41
$SD_l$	29.9	N.A.	39.2	28.6	N.A.	15.9
$df^e$	208	N.A.	40	238	N.A.	45
$CI_k$ upper $(x 10^{-4})^f$	26.07	N.A.	23.17	20.88	N.A.	19.45
$CI_k$ lower $(x 10^{-4})$	16.35	N.A.	13.59	14.34	N.A.	15.61
$CI_l$ upper	37.60	N.A.	10.22	5.06	N.A.	-8.95
$CI_l$ lower	-79.60	N.A.	-148.22	-107.06	N.A.	-73.05
$I$ residuals <sup>g</sup>	3.392	N.A.	0.117	2.707	N.A.	0.032

**FIGURE 33. BULK PINE LITTER, PLANTATIONS**  
**SINGLE EXPONENTIAL DECAY MODELS, WITHOUT LAG PERIODS**

$$[x = \exp(-kt)]$$

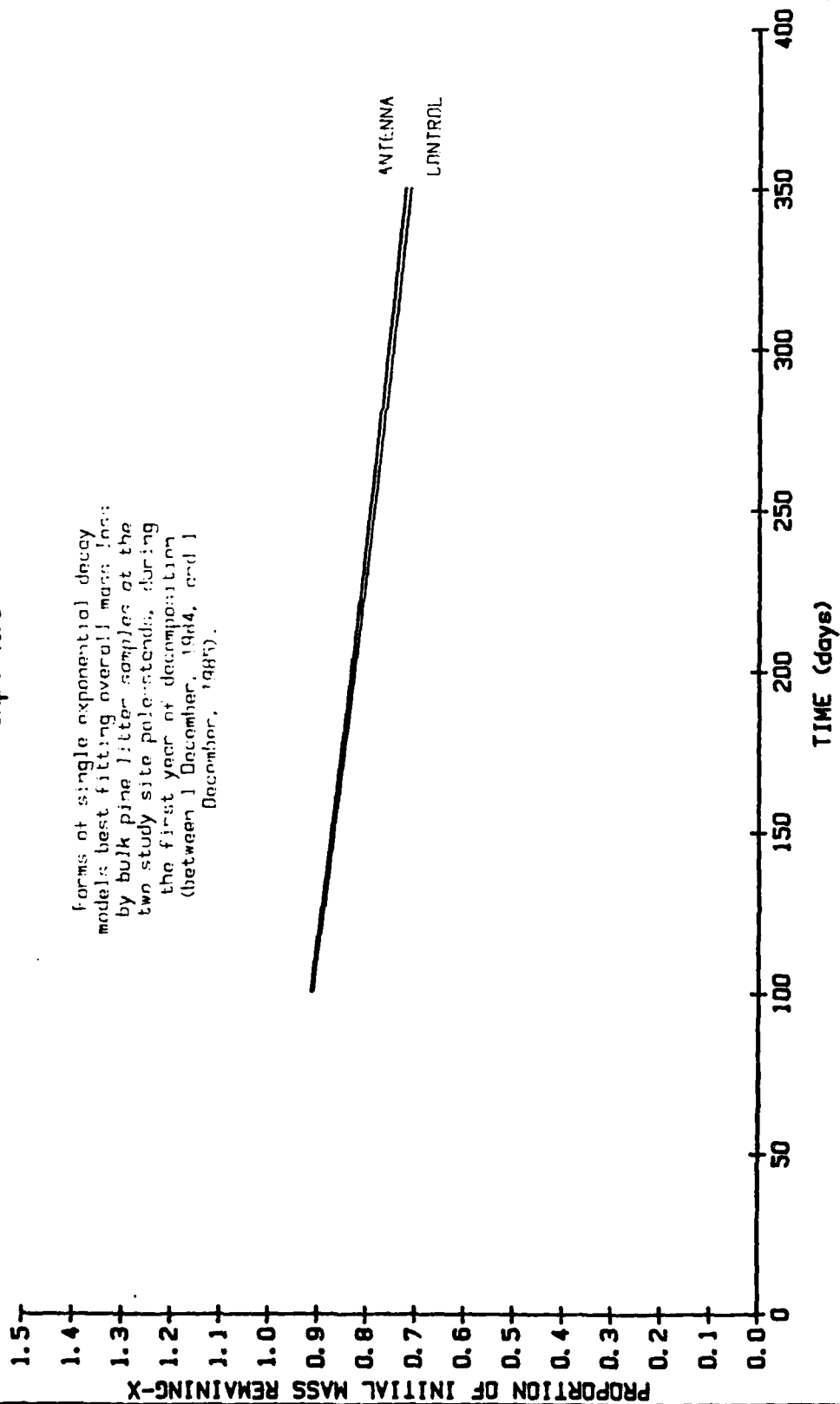
Forms of single exponential decay models best fitting overall mass loss by bulk pine litter samples at the three study site plantations, during the first year of decomposition between 1 December, 1984, and 1 December, 1985.



**FIGURE 34. BULK PINE LITTER, POLE-STANDS**  
**SINGLE EXPONENTIAL DECAY MODELS, WITHOUT LAG PERIODS**

$$[x = \exp(-kt)]$$

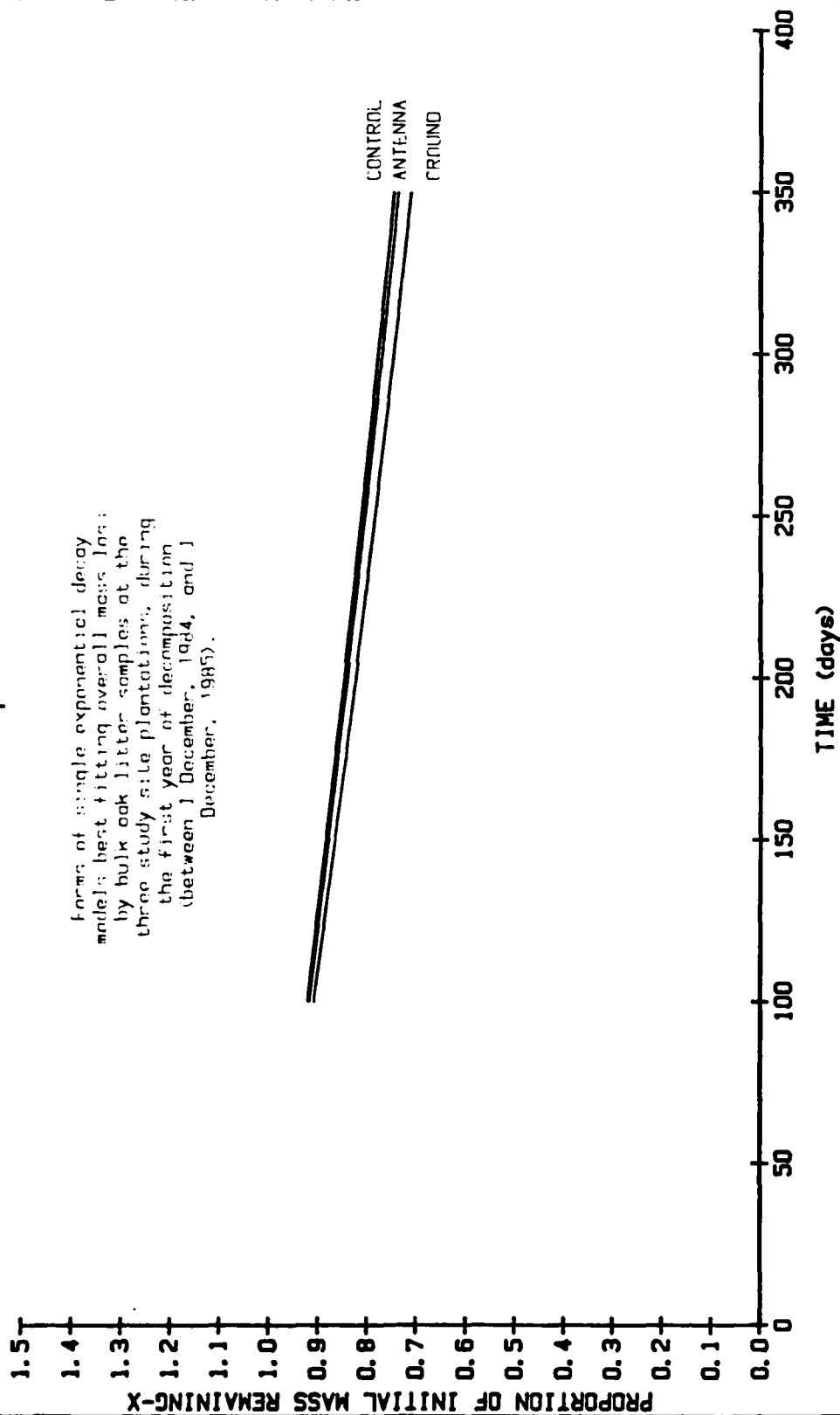
Forms of single exponential decay models best fitting overall mass loss by bulk pine litter samples at the two study site pole-stands, during the first year of decomposition (between 1 December, 1984, and 1 December, 1985).



**FIGURE 35. BULK OAK LITTER, PLANTATIONS**  
**SINGLE EXPONENTIAL DECAY MODELS, WITHOUT LAG PERIODS**

$$[x = \exp(-kt)]$$

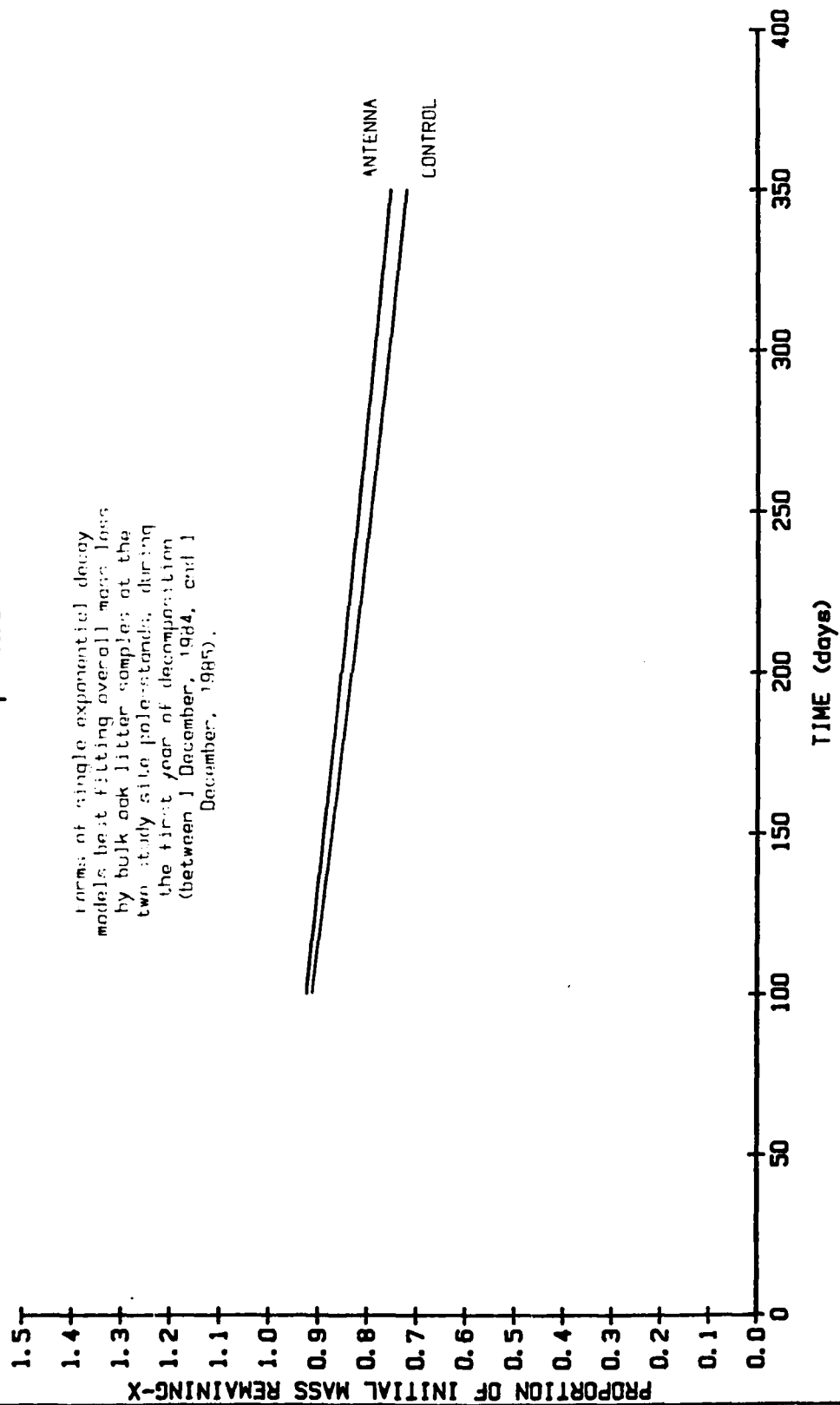
Forms of single exponential decay models best fitting overall mass loss by bulk oak litter samples at the three study site plantations, during the first year of decomposition (between 1 December, 1984, and 1 December, 1985).



**FIGURE 36. BULK OAK LITTER, POLE-STANDS**  
**SINGLE EXPONENTIAL DECAY MODELS, WITHOUT LAG PERIODS**

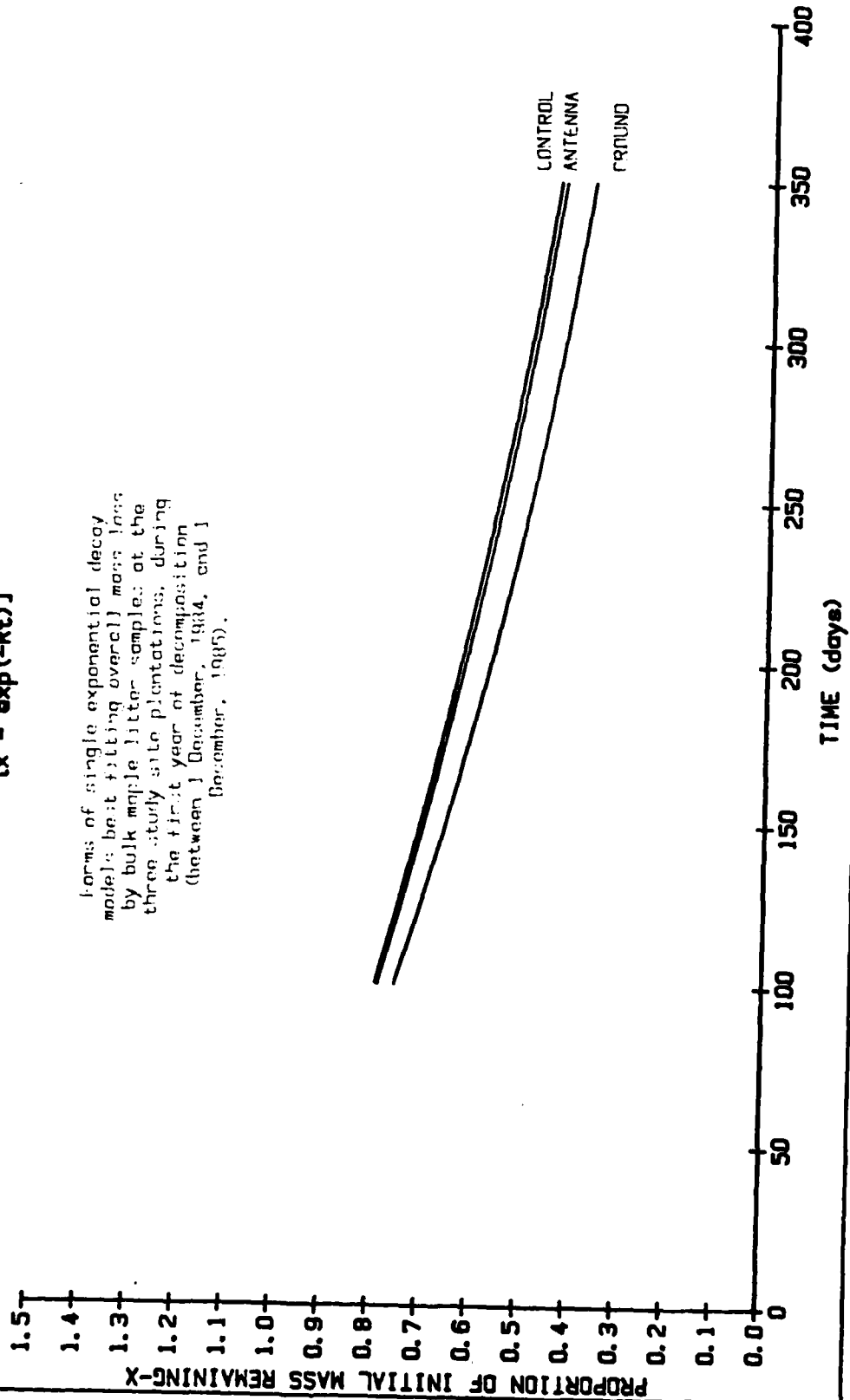
$$[x = \exp(-kt)]$$

Forms of single exponential decay models best fitting overall mass loss by bulk oak litter samples at the two study site pole-stands, during the first year of decomposition (between 1 December, 1984, and 1 December, 1985).



**FIGURE 37. BULK MAPLE LITTER, PLANTATIONS**  
**SINGLE EXPONENTIAL DECAY MODELS, WITHOUT LAG PERIODS**  
 $[x = \exp(-kt)]$

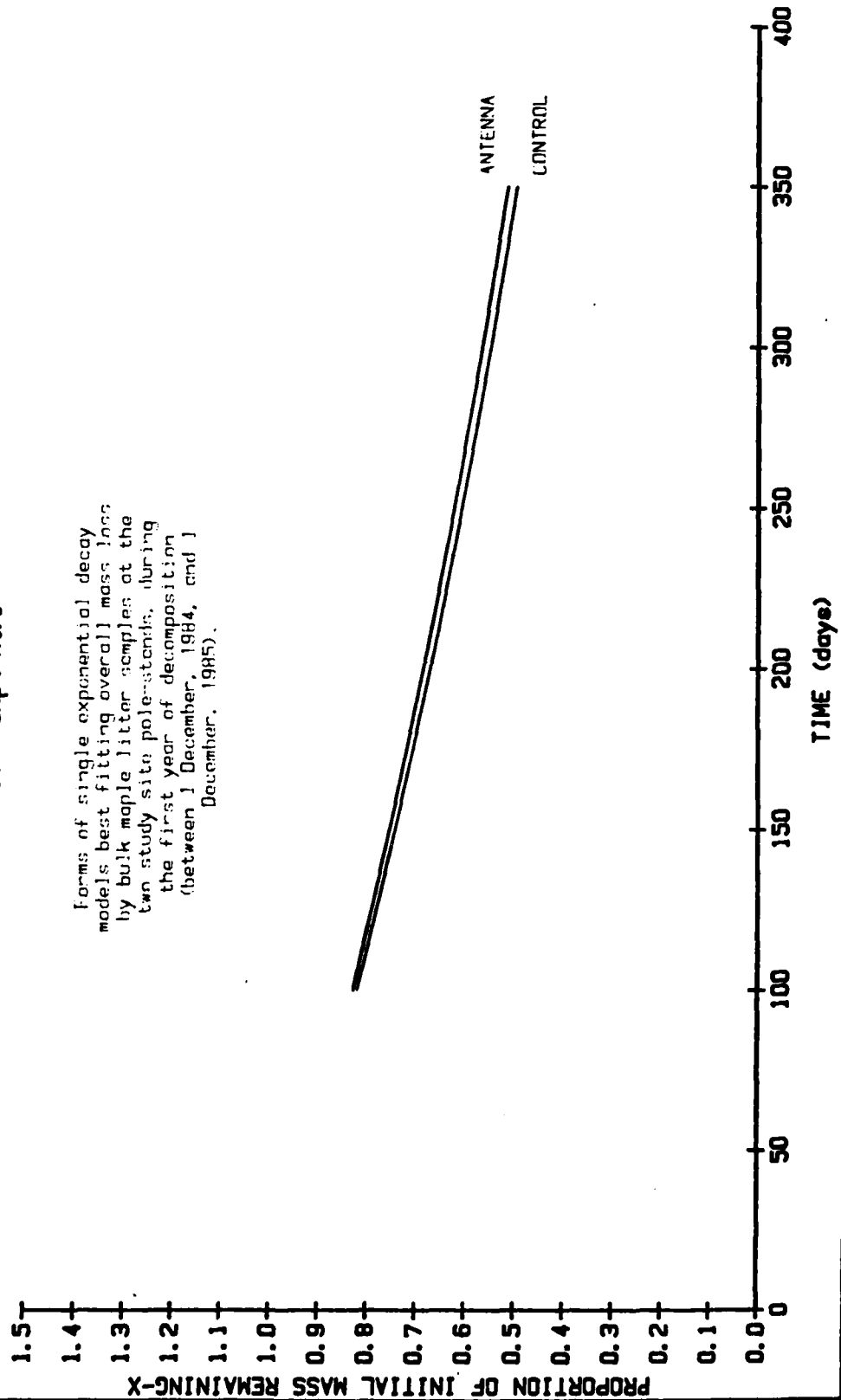
Forms of single exponential decay models; best fitting overall mass loss by bulk maple litter samples at the three study site plantations, during the first year of decomposition (between 1 December, 1984, and 1 December, 1985).



**FIGURE 38. BULK MAPLE LITTER, POLE-STANDS**  
**SINGLE EXPONENTIAL DECAY MODELS, WITHOUT LAG PERIODS**

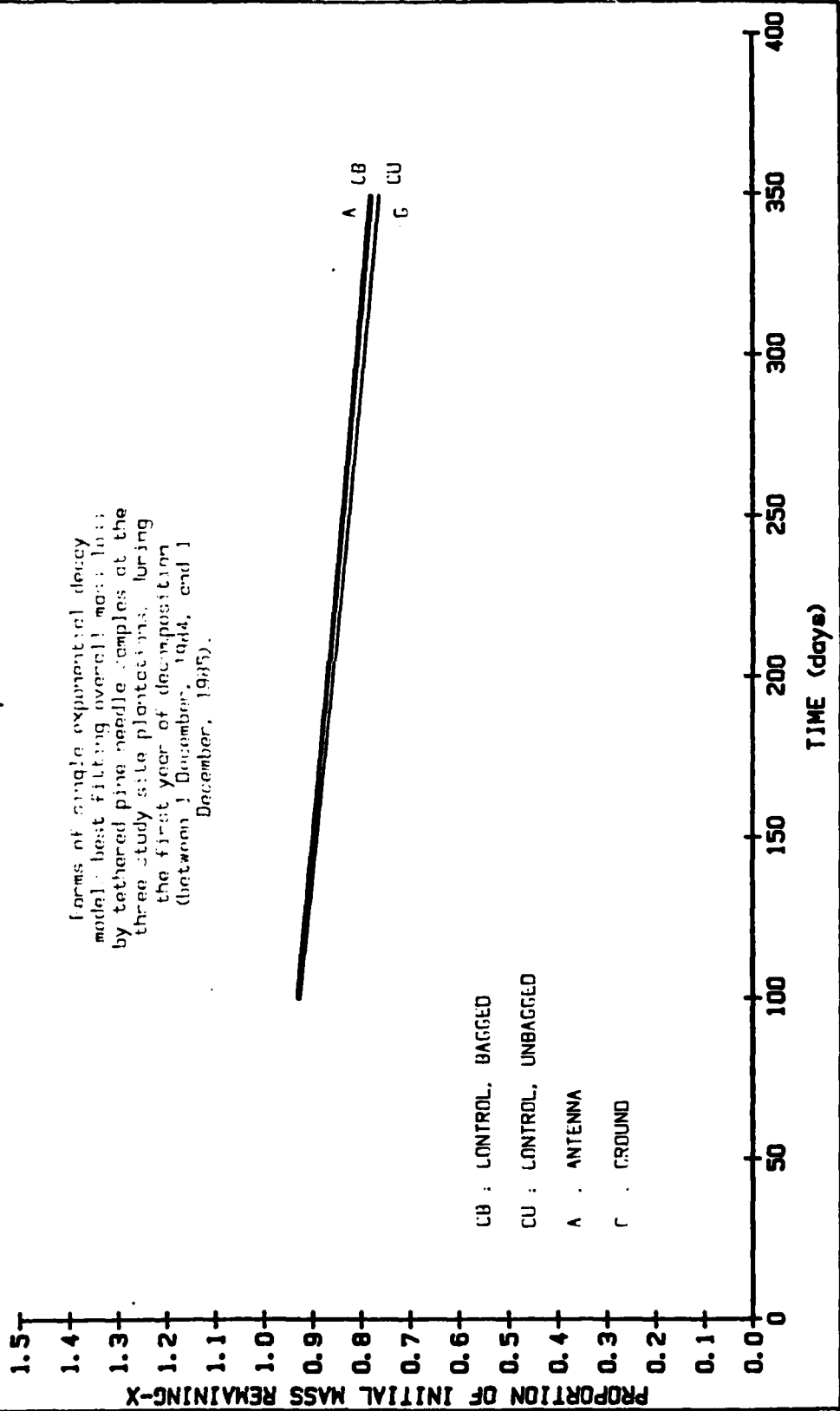
$$[x = \exp(-kt)]$$

Forms of single exponential decay models best fitting overall mass loss by bulk maple litter samples at the two study site pole-stands, during the first year of decomposition (between 1 December, 1984, and 1 December, 1985).





**FIGURE 39. TETHERED PINE NEEDLES, PLANTATIONS**  
**SINGLE EXPONENTIAL DECAY MODELS, WITHOUT LAG PERIODS**  
 $[x = \exp(-kt)]$

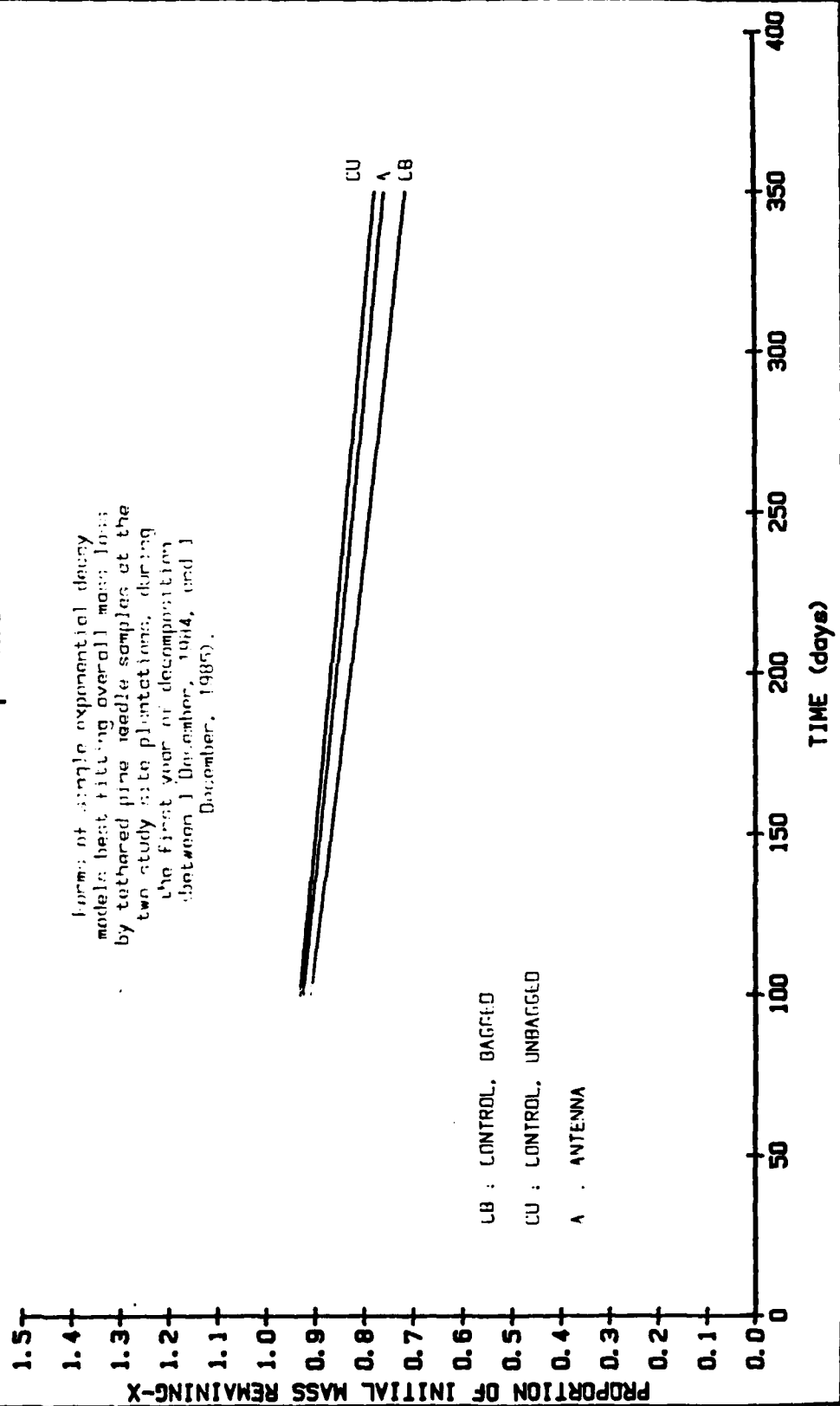


**FIGURE 40. TETHERED PINE NEEDLES, POLE-STANDS**

**SINGLE EXPONENTIAL DECAY MODELS, WITHOUT LAG PERIODS**

$$[x = \exp(-kt)]$$

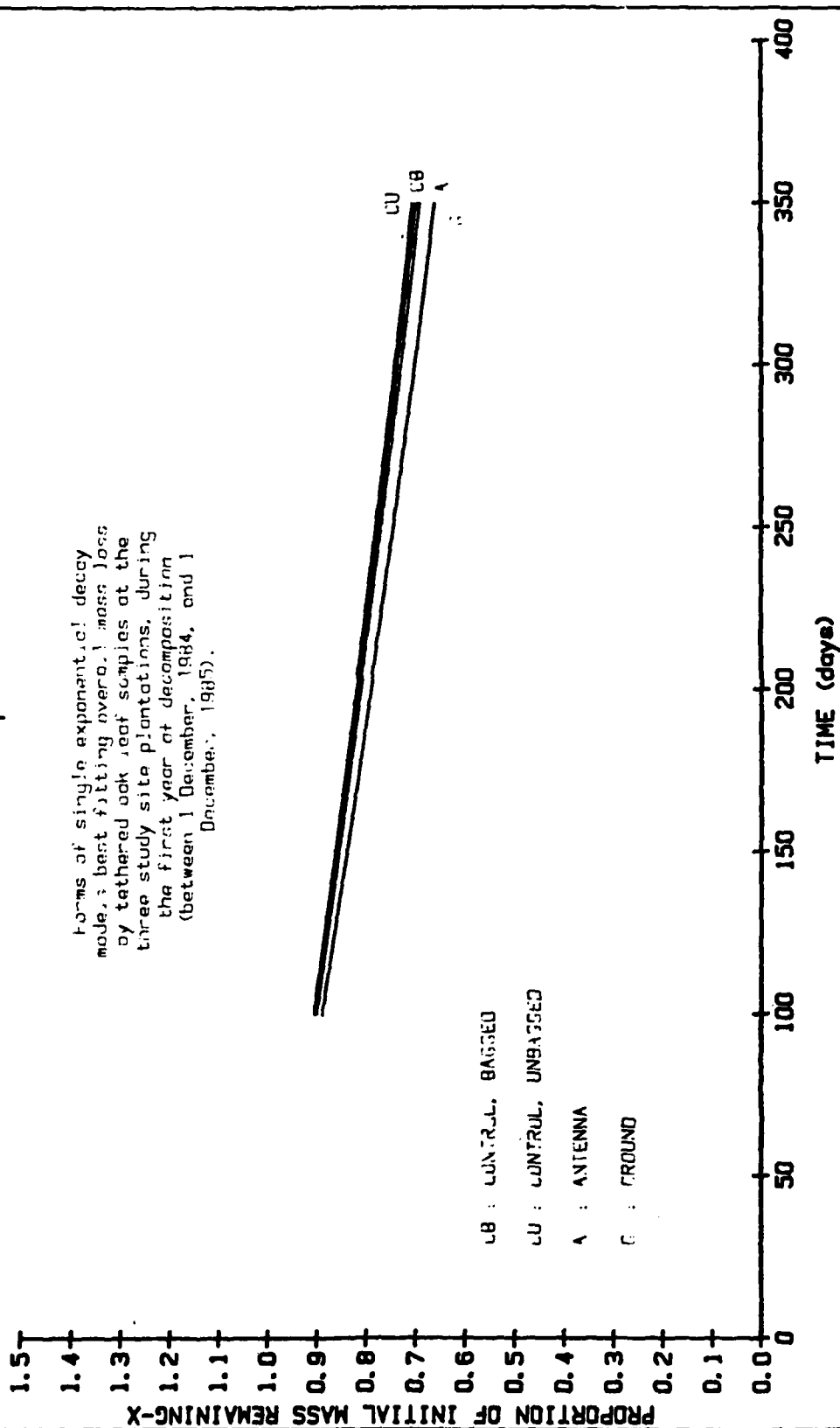
Forms of single exponential decay models best fitting overall mass loss by tethered pine needle samples at the two study site plantations, during the first year of decomposition (between 1 December, 1984, and 1 December, 1985).



**FIGURE 41. TETHERED OAK LEAVES, PLANTATIONS**  
**SINGLE EXPONENTIAL DECAY MODELS, WITHOUT LAG PERIODS**

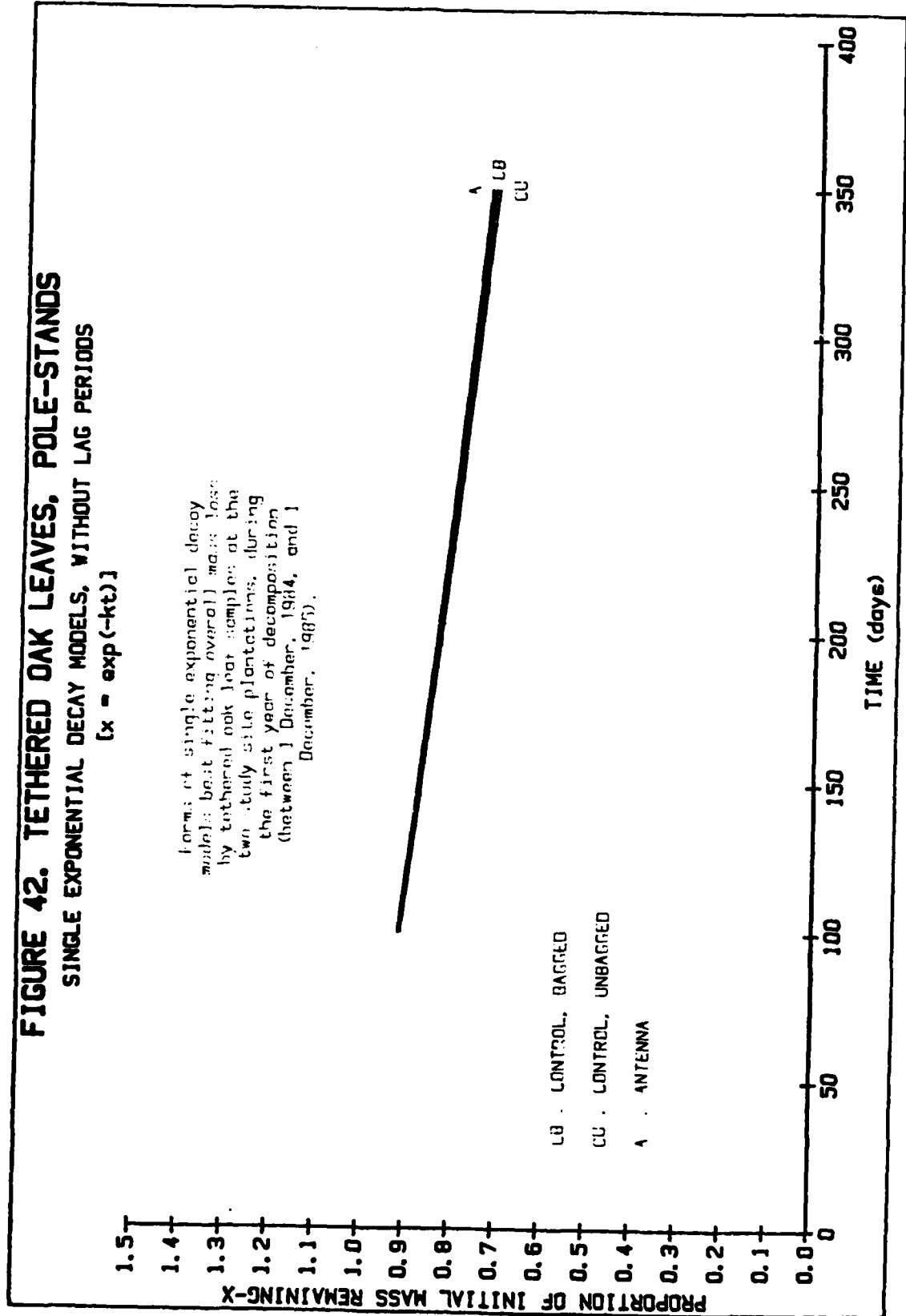
$$[x = \exp(-kt)]$$

Forms of single exponential decay models, best fitting overall mass loss by tethered oak leaf samples at the three study site plantations, during the first year of decomposition (between 1 December, 1984, and 1 December, 1985).

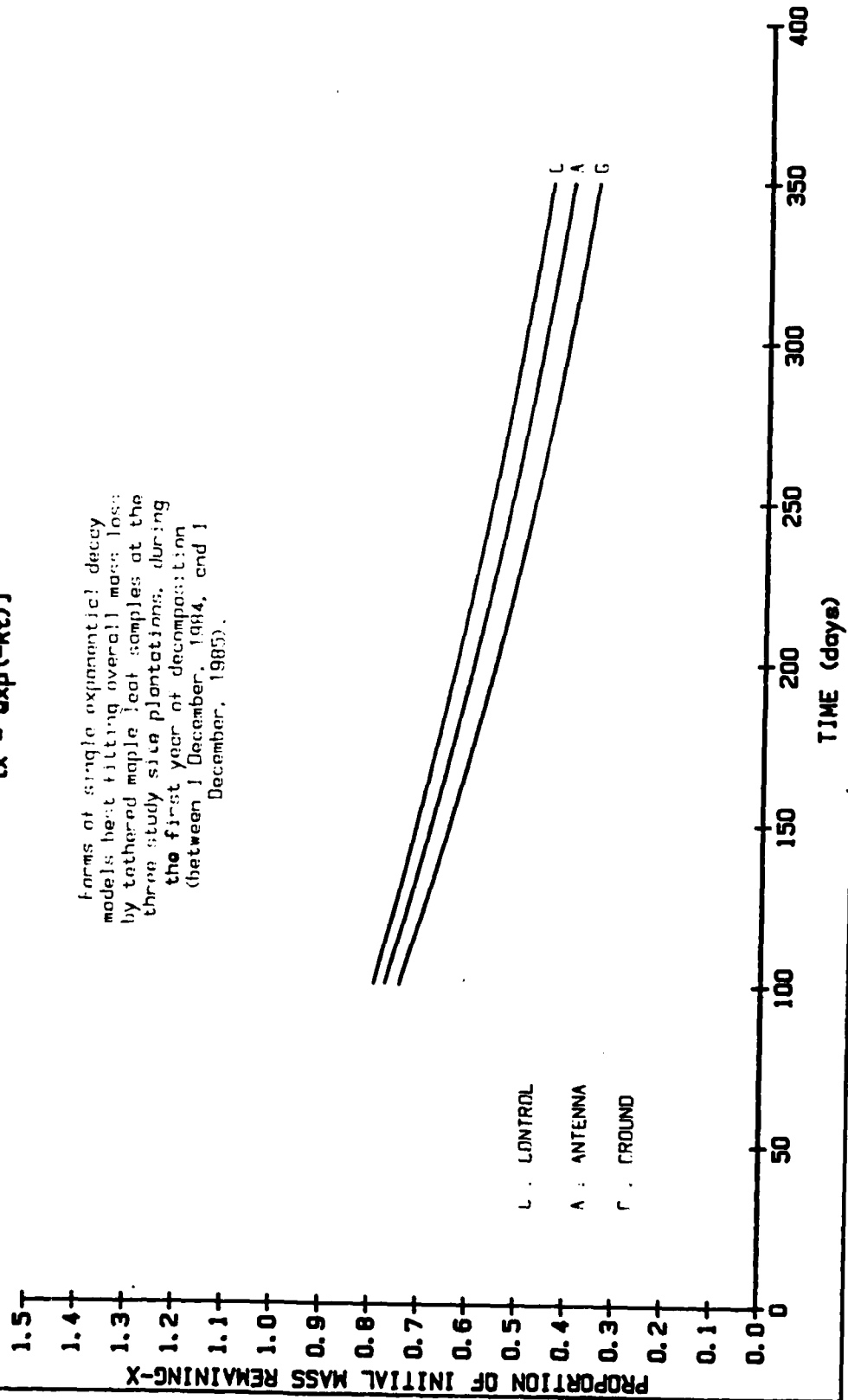


**FIGURE 42. TETHERED OAK LEAVES, POLE-STANDS**  
**SINGLE EXPONENTIAL DECAY MODELS, WITHOUT LAG PERIODS**  
 $[x = \exp(-kt)]$

Forms of single exponential decay models best fitting overall mass loss by tethered oak leaf samples at the two study site plantations, during the first year of decomposition (between 1 December, 1984, and 1 December, 1985).



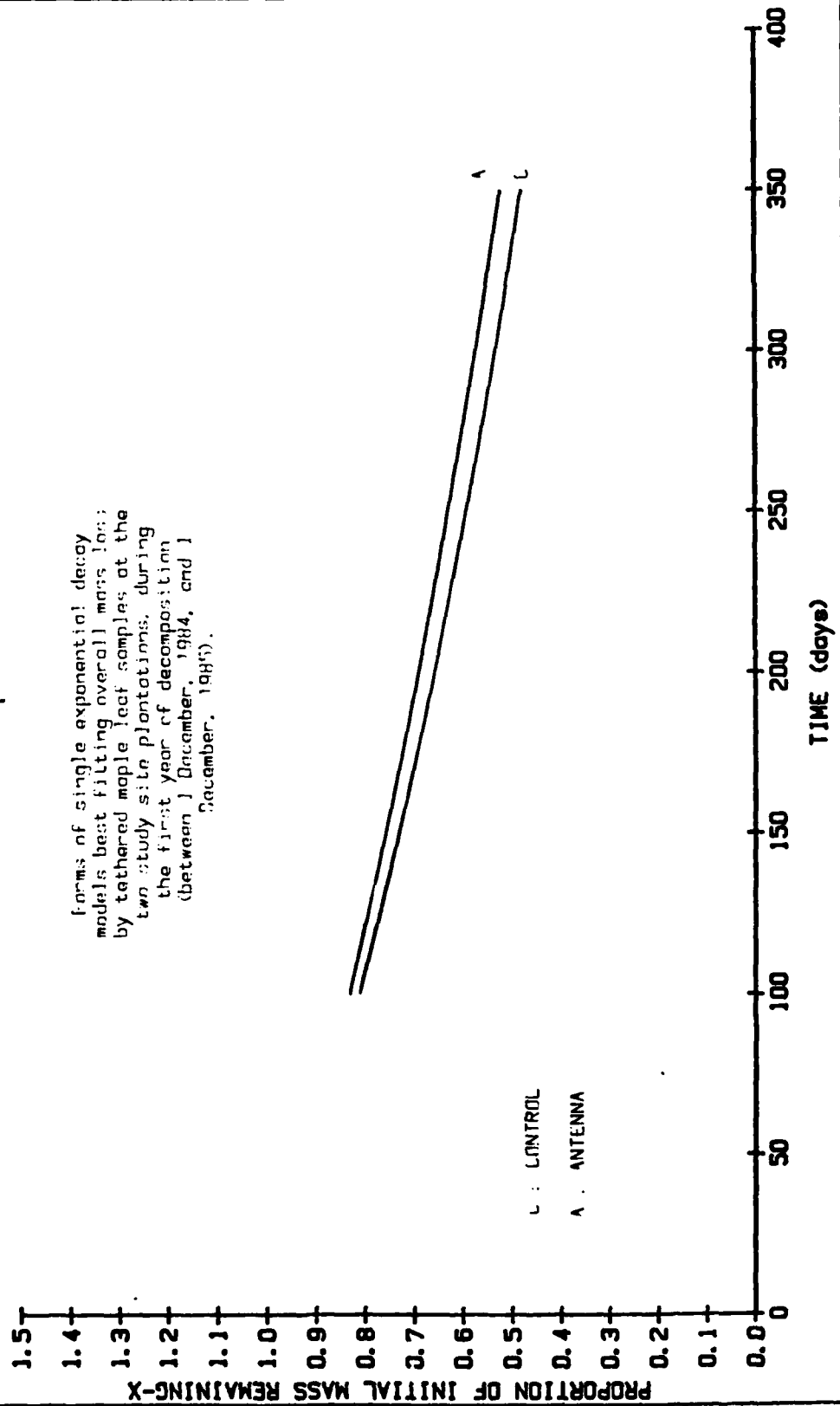
**FIGURE 43. TETHERED MAPLE LEAVES, PLANTATIONS**  
**SINGLE EXPONENTIAL DECAY MODELS, WITHOUT LAG PERIODS**  
 $[x = \exp(-kt)]$



**FIGURE 44. TETHERED MAPLE LEAVES, POLE-STANDS**  
**SINGLE EXPONENTIAL DECAY MODELS, WITHOUT LAG PERIODS**

$$[x = \exp(-kt)]$$

Forms of single exponential decay models best fitting overall mass loss by tethered maple leaf samples at the two study site plantations, during the first year of decomposition (between 1 December, 1984, and 1 December, 1985).



order to determine whether or not differences between lag periods or decomposition rate constants derived for different locations or methods were significant ( $\alpha = 0.05$ ). Differences in lag period between locations and between bulk and individual fascicle methods were not significant. The only apparently significant difference, in 1984, was between the Antenna site pole-stand and the two plantations, using the individual fascicle data and the model lacking a lag period. Because this model provided the poorest fit to the actual data, based on comparison of residual sums of squares, this difference in decomposition rate constants was presumed likely to be meaningless. It seemed quite clear that total pine litter mass loss proceeded at similar rates at both the Antenna and Ground sites, in both plantations and the pole-stand, and as determined by bulk litter samples and individual pine fascicles.

Comparison of rate constants and lag periods derived for the 1984 and 1985 mass loss data are limited to pine on the Antenna and Ground sites, as 1985 was our first year of experience with oak and maple, and also our first year of experience on the Control site. According to the model, without a lag period 1) individual pine fascicles and bulk pine samples decomposed more rapidly on the Ground site plantation in 1985 than in 1984; also, bulk pine samples at both the Antenna site plantation and pole-stand decomposed faster in 1985 than in 1984. If a lag period is included, the model suggests that only the plantation samples (at both sites) decomposed more slowly in 1984 than in 1985.

The single exponential models derived with the 1984 mass loss data suggested very little difference in decomposition rate between the three locations studied. Only two significant differences were noted: individual pine fascicles decomposed more rapidly in the Antenna pole-stand than on either plantation according to the model without a lag period. No significant difference in rate of decomposition between individual fascicles and bulk samples was detected by either of the single exponential models. Again in 1985, individual pine fascicle decomposition

apparently proceeded more rapidly in the Antenna pole-stand than in the Antenna site plantation according to the model without a lag period. Lag periods derived for the 1985 data were sufficiently different to cast doubt on the validity of comparing the associated decomposition rate constants. In marked contrast to the 1985 pine decomposition models, both individual leaves and bulk samples of oak and maple litter decomposed more rapidly at the Antenna and Ground plantations than in the Antenna pole-stand. At the Control site, only the bulk maple samples decomposed more rapidly in the plantation than in the pole-stand. Individual pine fascicles decomposed more rapidly in the Control pole-stand than in the Control site plantation, as might be expected.

Both individual leaf and bulk maple samples always decomposed at much faster rates than did similar samples for either pine or oak, regardless of location. In most cases, individual oak leaves, but not bulk oak samples, decomposed faster than did similar pine samples at each study location.

Unbagged pine fascicles decomposed more slowly than either the bagged individual fascicles or the bagged bulk samples in the Control site pole-stand. In the Control site plantation, only the bulk samples decomposed significantly faster than the individual fascicles. Unbagged oak leaves decomposed at approximately the same rate as bagged individual oak leaves and bulk oak samples.

The possibility that a double exponential model might better fit the total mass loss data was also explored, in both 1984 and 1985, using BMDPAR. The form of the model tested is:

$$X = Ae^{-k_1t} + (1-A)e^{-k_2t},$$

where  $A$  is the proportion of the initial mass relatively easily removed,  $(1-A)$  is the proportion representing more recalcitrant components (e.g., cellulose, lignin),  $k_1$  and  $k_2$  are rate constants for the decomposition of the two fractions of the initial mass, and  $t$  is the time elapsed since initiation of decomposition (Hunt 1977). A lag factor was also incorporated by substituting  $(t-1)$  for  $t$  in the equation above. Initial values for  $A$ ,  $k_1$ , and



$k_2$  were set at 0.223, 0.0409, and 0.000971, based on data collected for oak leaves by Pinck et al. (1950). Attempts to fit double exponential models to weight loss data, with or without a lag period, all failed. In every case, the iterative process led to an extremely low value for the easily decomposed proportion of the initial mass. At best, the program appeared to approach a single exponential model in form. This is understandable, since the rationale for using a double exponential model is to permit the rapid early decomposition of a portion of the substrate.

The major weakness in the case for our use of exponential models is the fact that they assume a uniform environment throughout the period (t) of study. In our case, a long, cold winter beneath a heavy snowpack is followed by a cool, wet spring, a mild, dry mid-summer, and a cool, wet autumn. As a result, values derived from exponential models for "lag period" and "decomposition rate constants" probably have very little biological meaning, and serve mainly to lower the residual sum of squares. This would explain why the single exponential models derived for our three species of litter have such radically different and apparently meaningless "lag periods" while providing lower residual sums of squares than the single exponential models without lag periods. Any benefit which might be derived from reduction of residual sums of squares by adding a lag period, however, seems to be more than offset by the confounding effect of a lag period on comparison of  $k$  values. Even when lag period differences are not statistically significant, they affect the  $k$  values with which they are derived. In light of the above considerations, we will continue to report and compare  $k$  values for single exponential models without lag periods in the future, because they do provide a means by which to compare the progress of decomposition within treatments over the year.

All 666 bulk samples retrieved between May and December, 1985, have been ground and are currently being analyzed in the Forest Soils Analysis Laboratory at MTU. Tables 15 through 17 present nitrogen flux data for the first half of the 1985 season. Figures 45 through 59 present the same data graphically. As of 1

Table 15. Mean proportions<sup>a</sup> of initial total N content remaining at different times in 1985, for bulk red pine foliar litter samples disbursed in early December, 1984.

Sample Retrieval Date	Ground Site Plantation	Antenna Site	
		Plantation	Pole-stand
30 April	0.98 (0.06) <sup>b</sup>	1.01 (0.04)	1.06 (0.12)
2 June	0.96 (0.08)	1.00 (0.05)	1.05 (0.06)
3 July	1.14 (0.09)	1.09 (0.07)	1.22 (0.08)
31 July	0.99 (0.06)	1.01 (0.06)	1.17 (0.12)
27 August <sup>c</sup>			
31 October <sup>c</sup>			
2 November <sup>c</sup>			
1 December <sup>c</sup>			

Table 15. (cont)

Sample Retrieval Date	Control Site	
	Plantation	Pole-stand
30 April	1.15 (0.15)	0.98 (0.07)
2 June	1.09 (0.08)	0.97 (0.13)
3 July	1.13 (0.06)	1.06 (0.09)
31 July	1.18 (0.10)	1.01 (0.07)
27 August <sup>c</sup>		
31 October <sup>c</sup>		
2 November <sup>c</sup>		
1 December <sup>c</sup>		

a/ Proportion ( $X=W_1/W_0$ ), where  $W_0$  and  $W_1$  are the percentages of N (w/w, 30°C) multiplied by total dry weight (30°C) for time 0 and time 1, respectively.

b/ standard deviation

c/ These data are not yet available.

Table 16. Mean proportion<sup>a</sup> of initial total N content remaining at different times in 1985, for bulk northern red oak foliar litter samples disburied in early December, 1984.

Sample Retrieval Date	Ground Site Plantation	Antenna Site	
		Plantation	Pole-stand
30 April	1.11 (0.08) <sup>b</sup>	1.09 (0.07)	1.19 (0.11)
2 June	1.09 (0.03)	1.22 (0.15)	1.28 (0.09)
3 July	1.17 (0.08)	1.20 (0.12)	1.35 (0.12)
31 July	1.28 (0.17)	1.17 (0.04)	1.22 (0.06)
27 August <sup>c</sup>			
31 October <sup>c</sup>			
2 November <sup>c</sup>			
1 December <sup>c</sup>			

Table 16. (cont)

Sample Retrieval Date	Control Site	
	Plantation	Pole-stand
30 April	1.13 (0.11)	1.17 (0.11)
2 June	1.11 (0.06)	1.13 (0.11)
3 July	1.18 (0.05)	1.30 (0.04)
31 July	1.23 (0.06)	1.23 (0.09)
27 August <sup>c</sup>		
31 October <sup>c</sup>		
2 November <sup>c</sup>		
1 December <sup>c</sup>		

a/ Proportion ( $X=W_1/W_0$ ), where  $W_0$  and  $W_1$  are the percentages of N (w/w, 30°C) multiplied by total dry weight (30°C) for time 0 and time 1, respectively.

b/ standard deviation

c/ These data are not yet available.

Table 17. Mean proportion<sup>a</sup> of initial total N content remaining at different times in 1985, for bulk red maple foliar litter samples disbursed in early December, 1984.

Sample Retrieval Date	Ground Site Plantation	Antenna Site	
		Plantation	Pole-stand
30 April	0.94 (0.05) <sup>b</sup>	0.93 (0.09)	1.13 (0.13)
2 June	0.91 (0.07)	1.04 (0.10)	1.17 (0.08)
3 July	0.96 (0.08)	1.08 (0.13)	1.24 (0.08)
31 July	0.95 (0.06)	0.96 (0.11)	1.18 (0.08)
27 August <sup>c</sup>			
31 October <sup>c</sup>			
2 November <sup>c</sup>			
1 December <sup>c</sup>			

Table 17. (cont)

Sample Retrieval Date	Control Site	
	Plantation	Pole-stand
30 April	1.06 (0.13)	1.04 (0.05)
2 June	1.13 (0.10)	1.18 (0.09)
3 July	1.12 (0.06)	1.25 (0.06)
31 July	1.13 (0.10)	1.20 (0.07)
27 August <sup>c</sup>		
31 October <sup>c</sup>		
2 November <sup>c</sup>		
1 December <sup>c</sup>		

a/ Proportion ( $X=W_1/W_0$ ), where  $W_0$  and  $W_1$  are the percentages of N (w/w, 30°C) multiplied by total dry weight (30°C) for time 0 and time 1, respectively.

b/ standard deviation

c/ These data are not yet available.

**FIGURE 45. BULK PINE LITTER, GROUND SITE - PLANTATION**  
PROPORTION (X) OF INITIAL NITROGEN MASS REMAINING

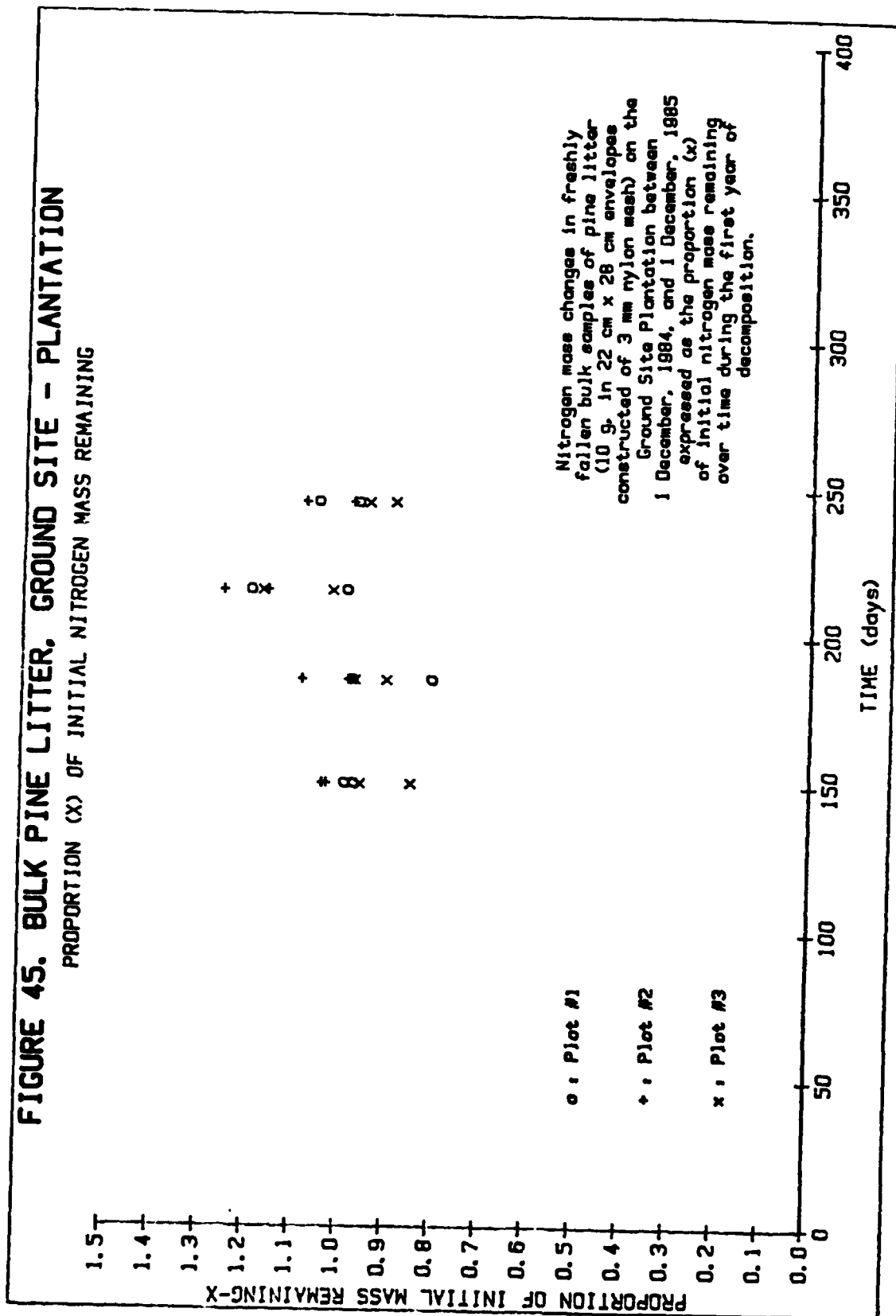
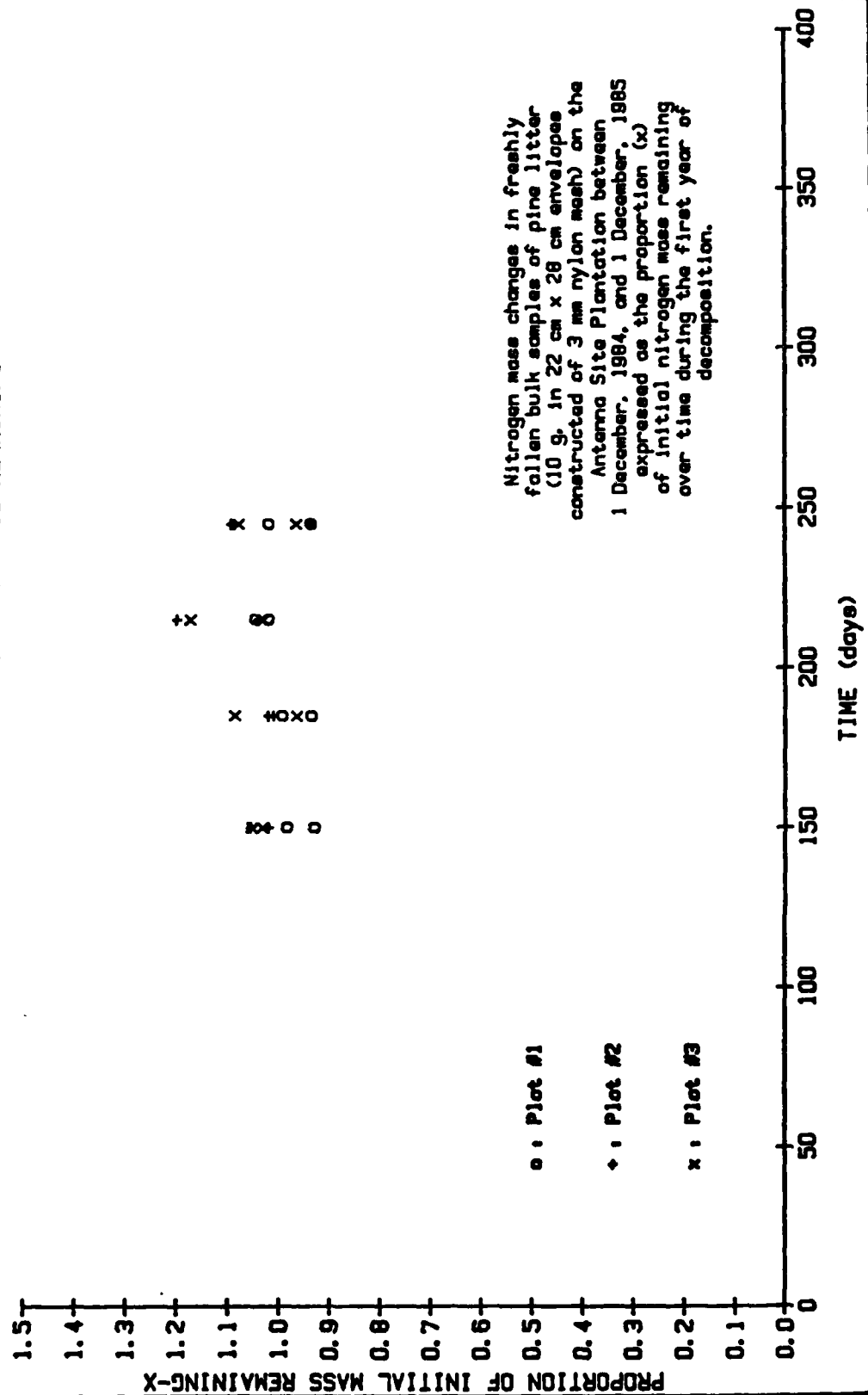


FIGURE 46. BULK PINE LITTER, ANTENNA SITE - PLANTATION

PROPORTION (X) OF INITIAL NITROGEN MASS REMAINING



**FIGURE 47. BULK PINE LITTER, ANTENNA SITE - POLE-STAND**  
 PROPORTION (X) OF INITIAL NITROGEN MASS REMAINING

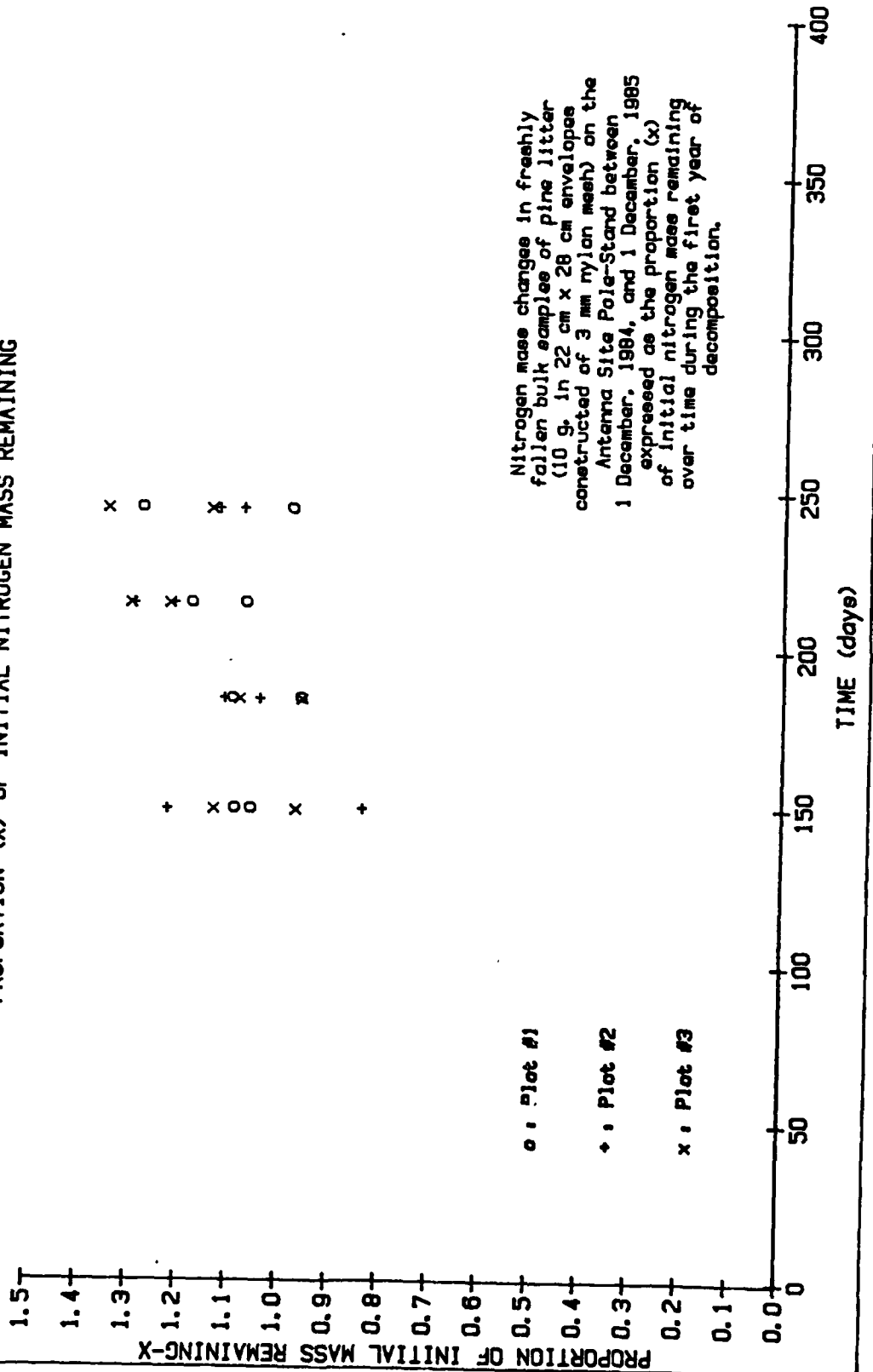
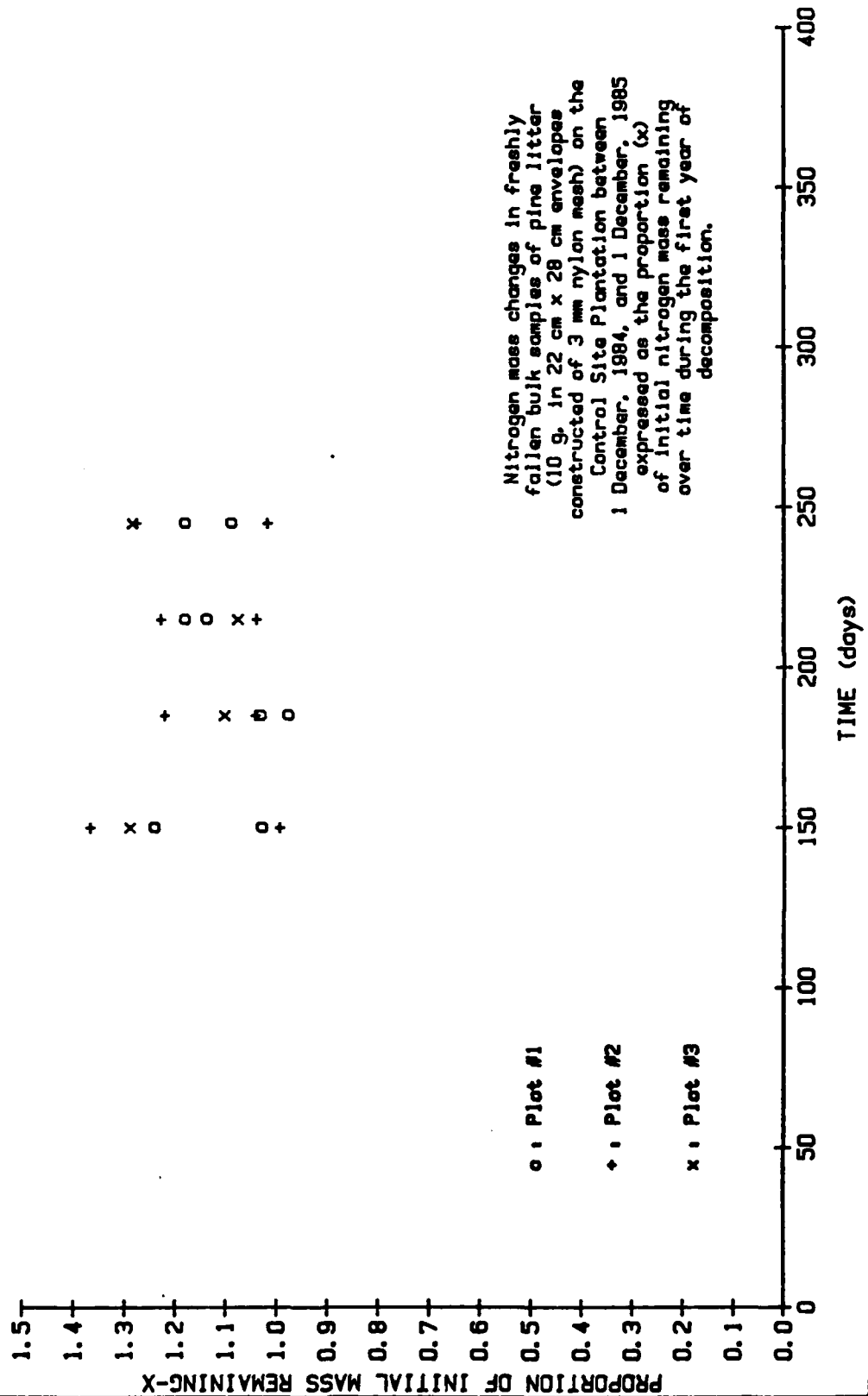


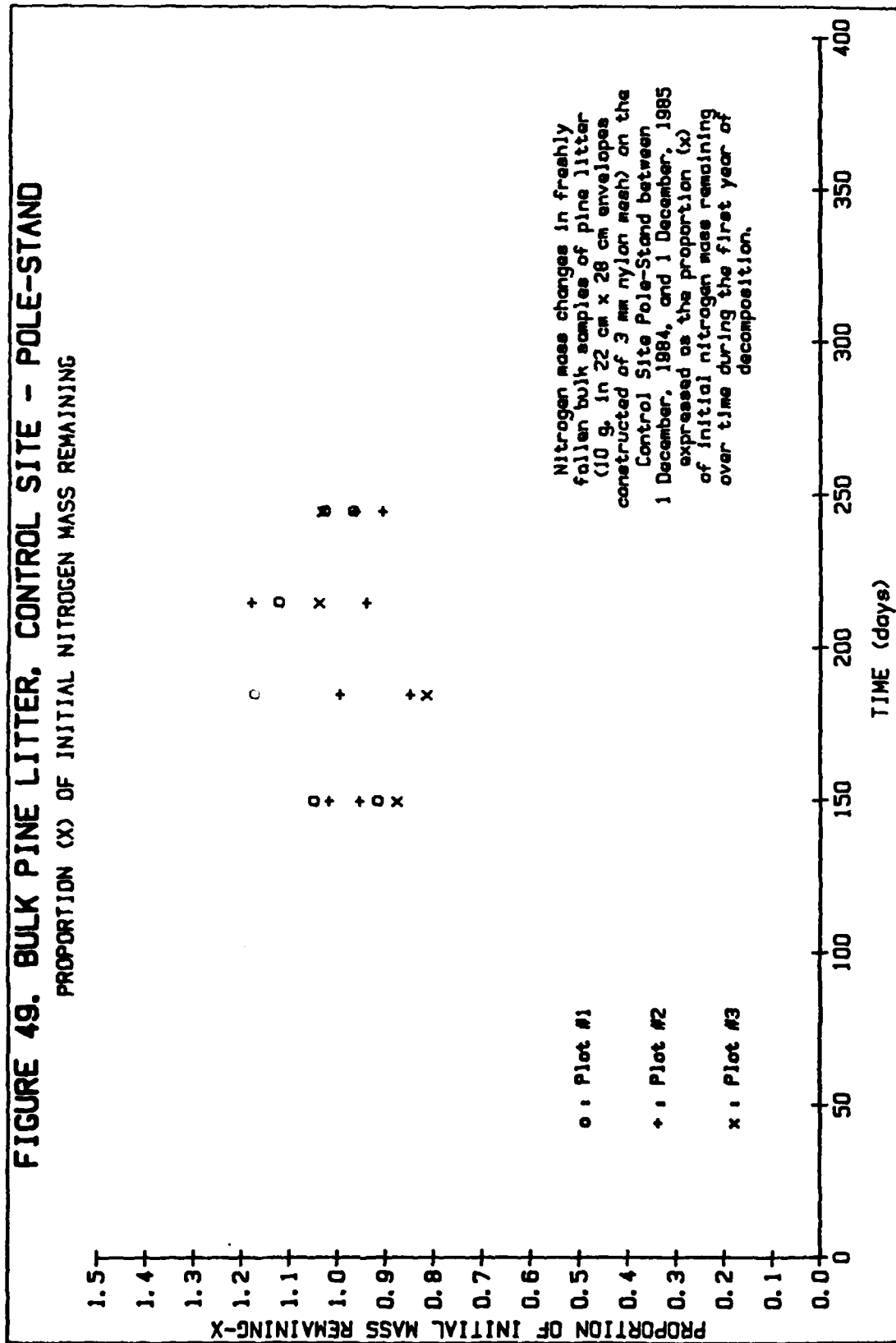
FIGURE 48. BULK PINE LITTER, CONTROL SITE - PLANTATION

PROPORTION (X) OF INITIAL NITROGEN MASS REMAINING

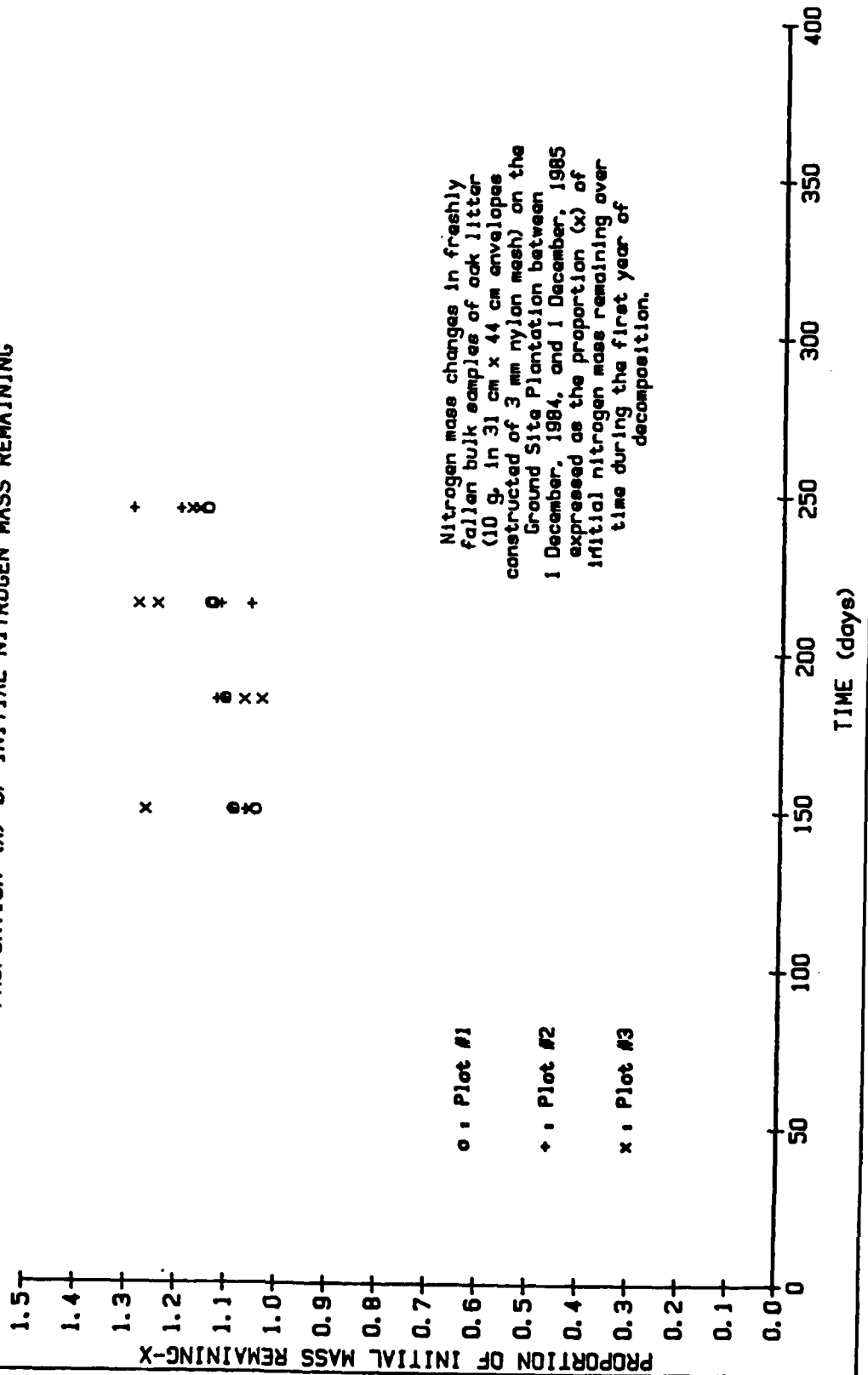


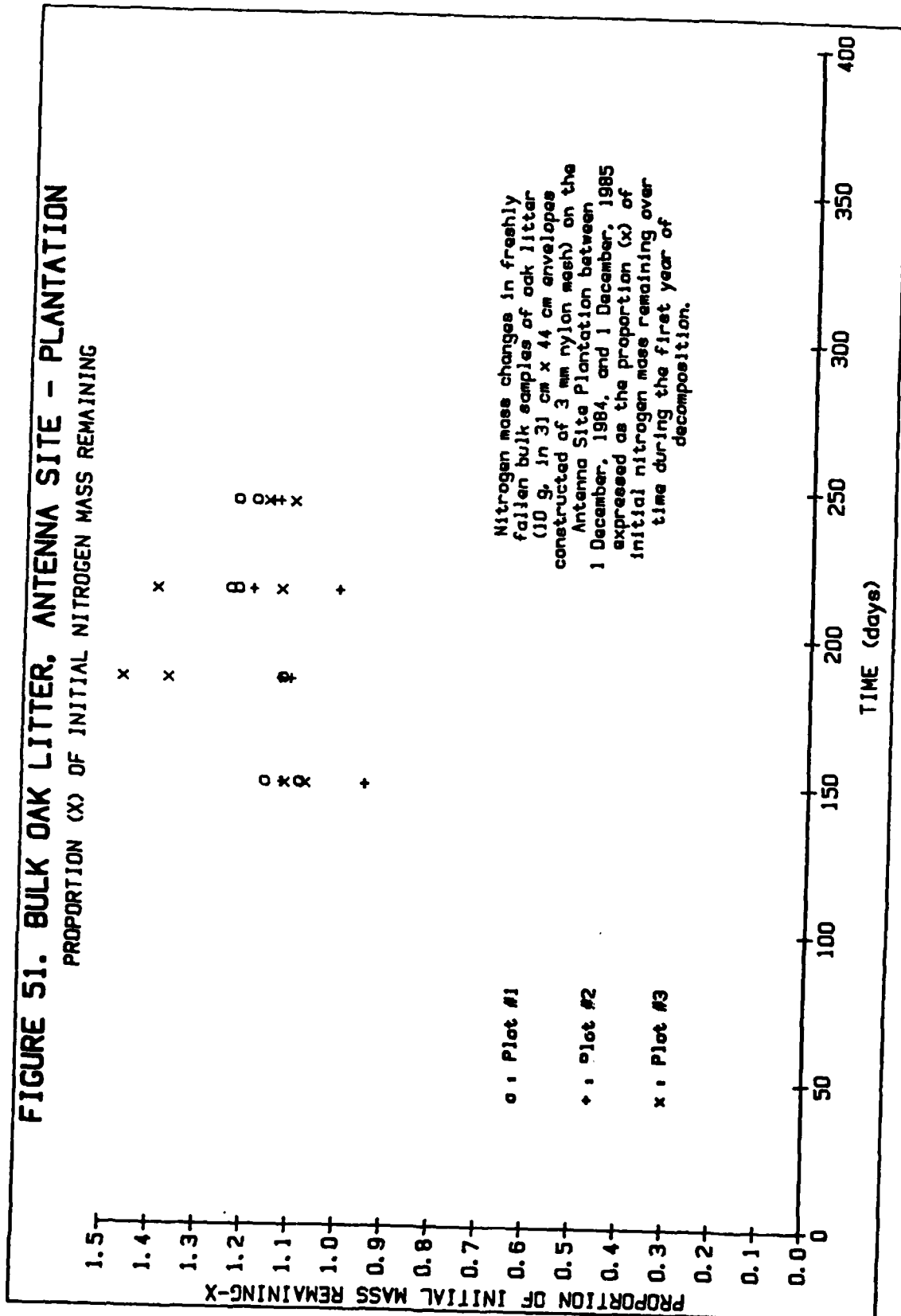


**FIGURE 49. BULK PINE LITTER, CONTROL SITE - POLE-STAND**  
 PROPORTION (X) OF INITIAL NITROGEN MASS REMAINING



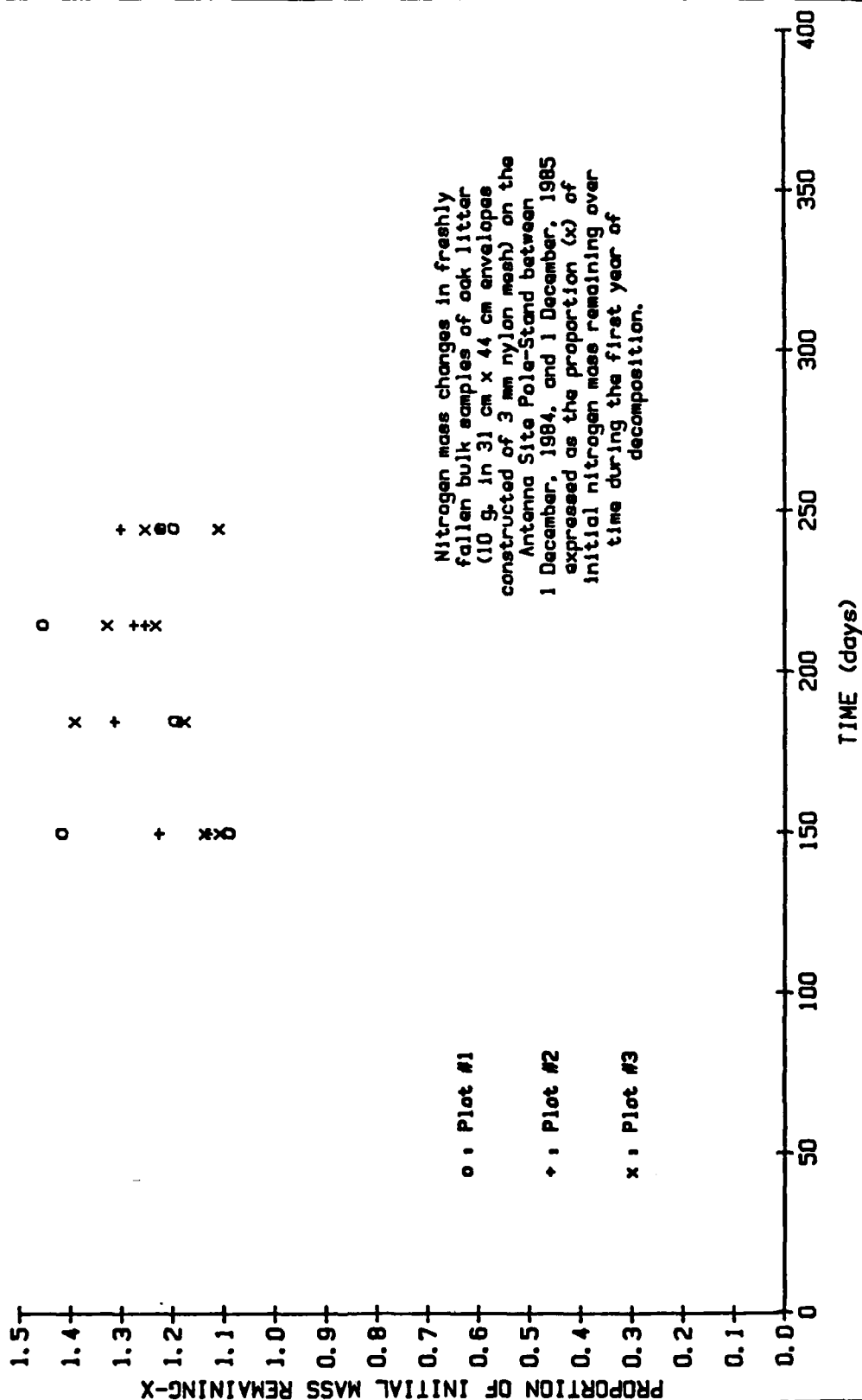
**FIGURE 50. BULK OAK LITTER, GROUND SITE - PLANTATION**  
PROPORTION (X) OF INITIAL NITROGEN MASS REMAINING

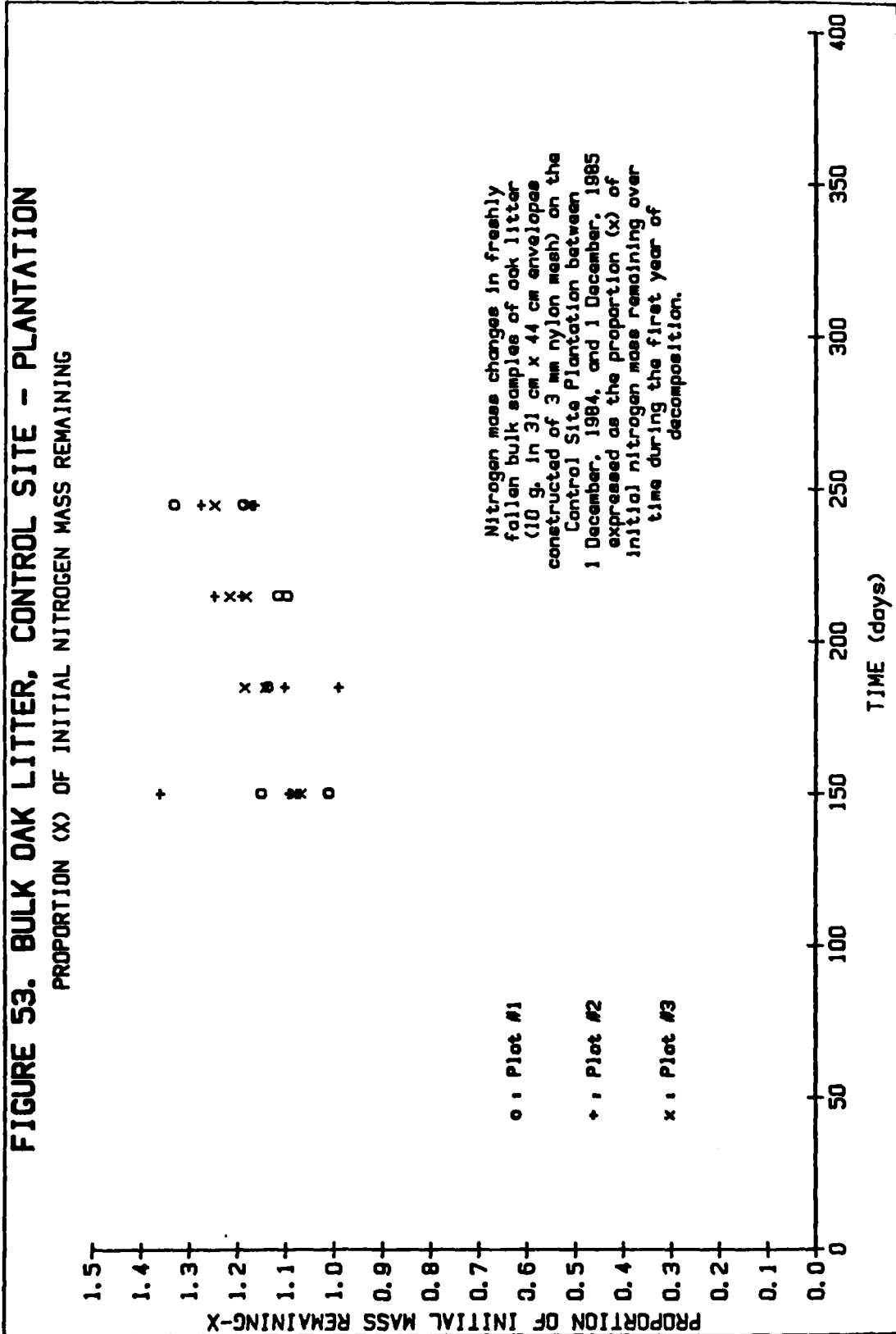




**FIGURE 52. BULK OAK LITTER, ANTENNA SITE - POLE-STAND**

PROPORTION (X) OF INITIAL NITROGEN MASS REMAINING





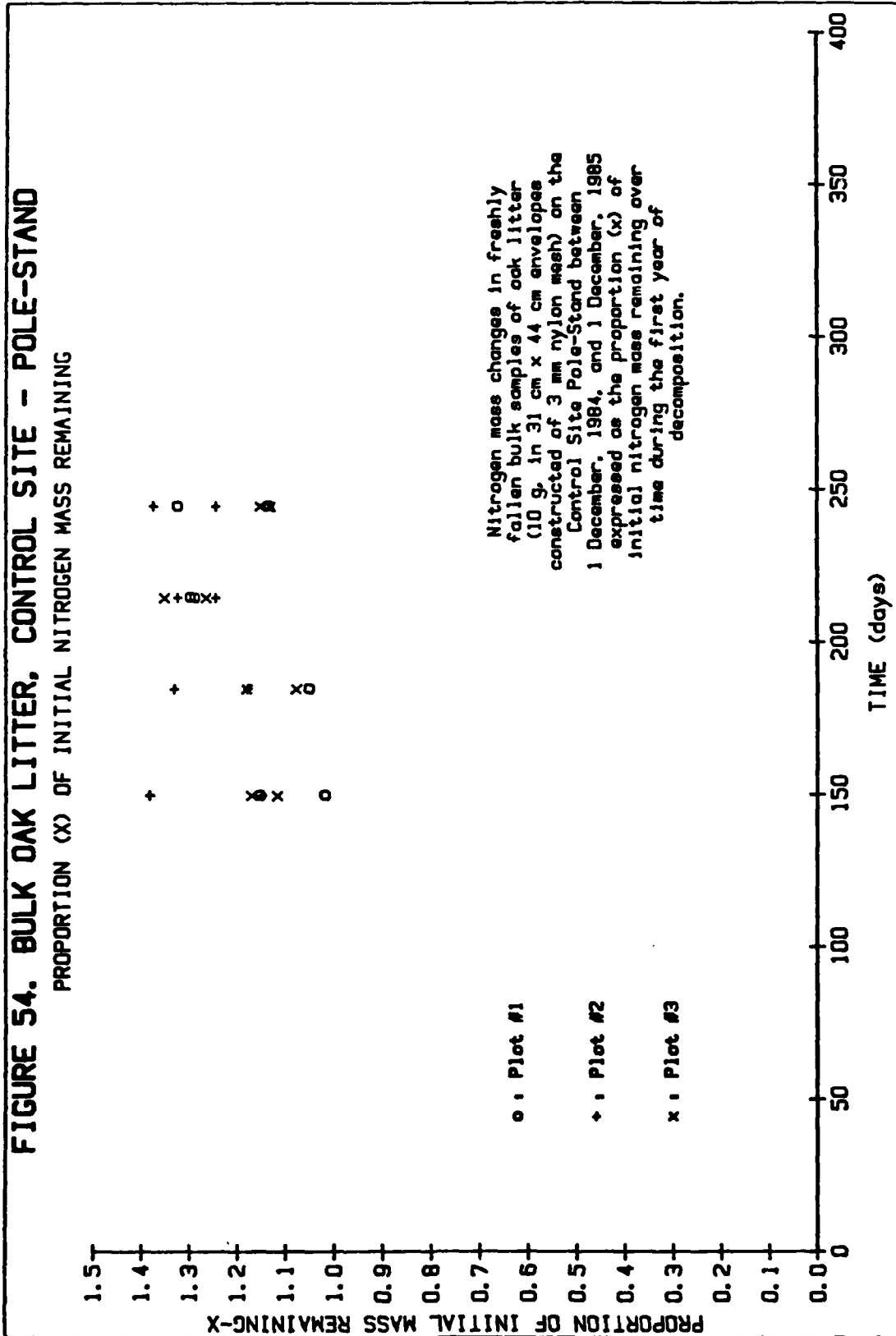
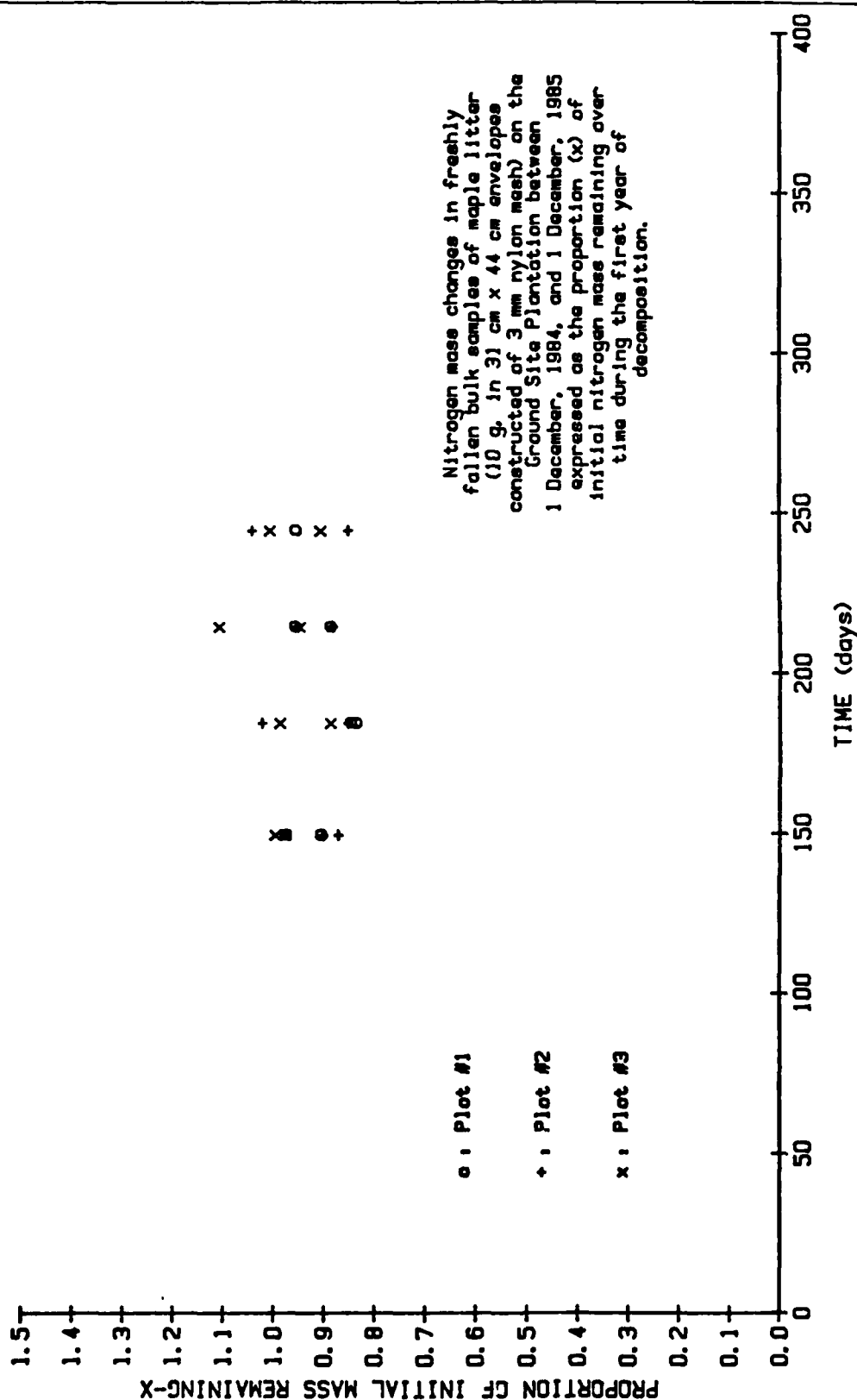
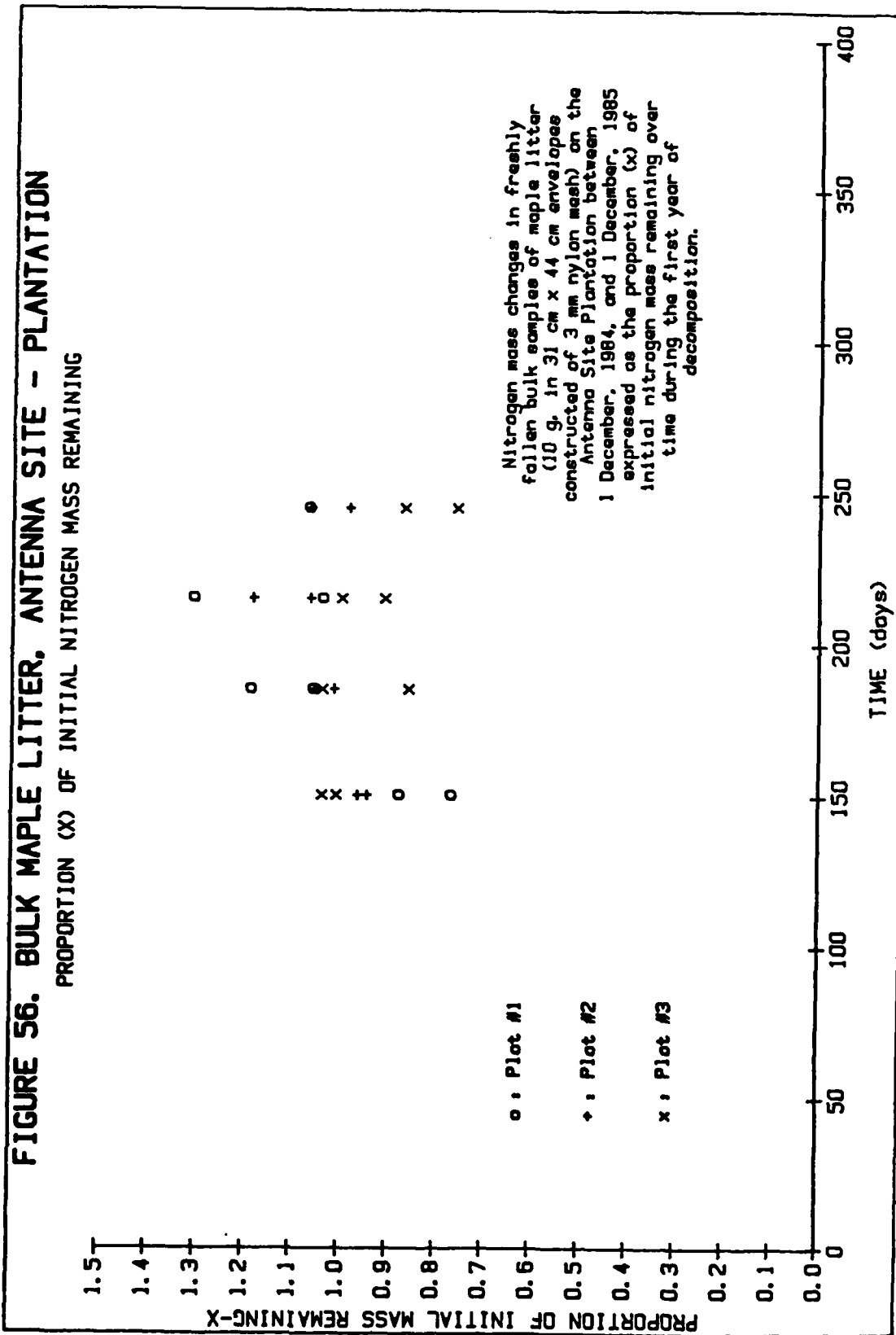


FIGURE 55. BULK MAPLE LITTER, GROUND SITE - PLANTATION

PROPORTION (X) OF INITIAL NITROGEN MASS REMAINING







**FIGURE 57. BULK MAPLE LITTER, ANTENNA SITE - POLE-STAND**  
PROPORTION (X) OF INITIAL NITROGEN MASS REMAINING

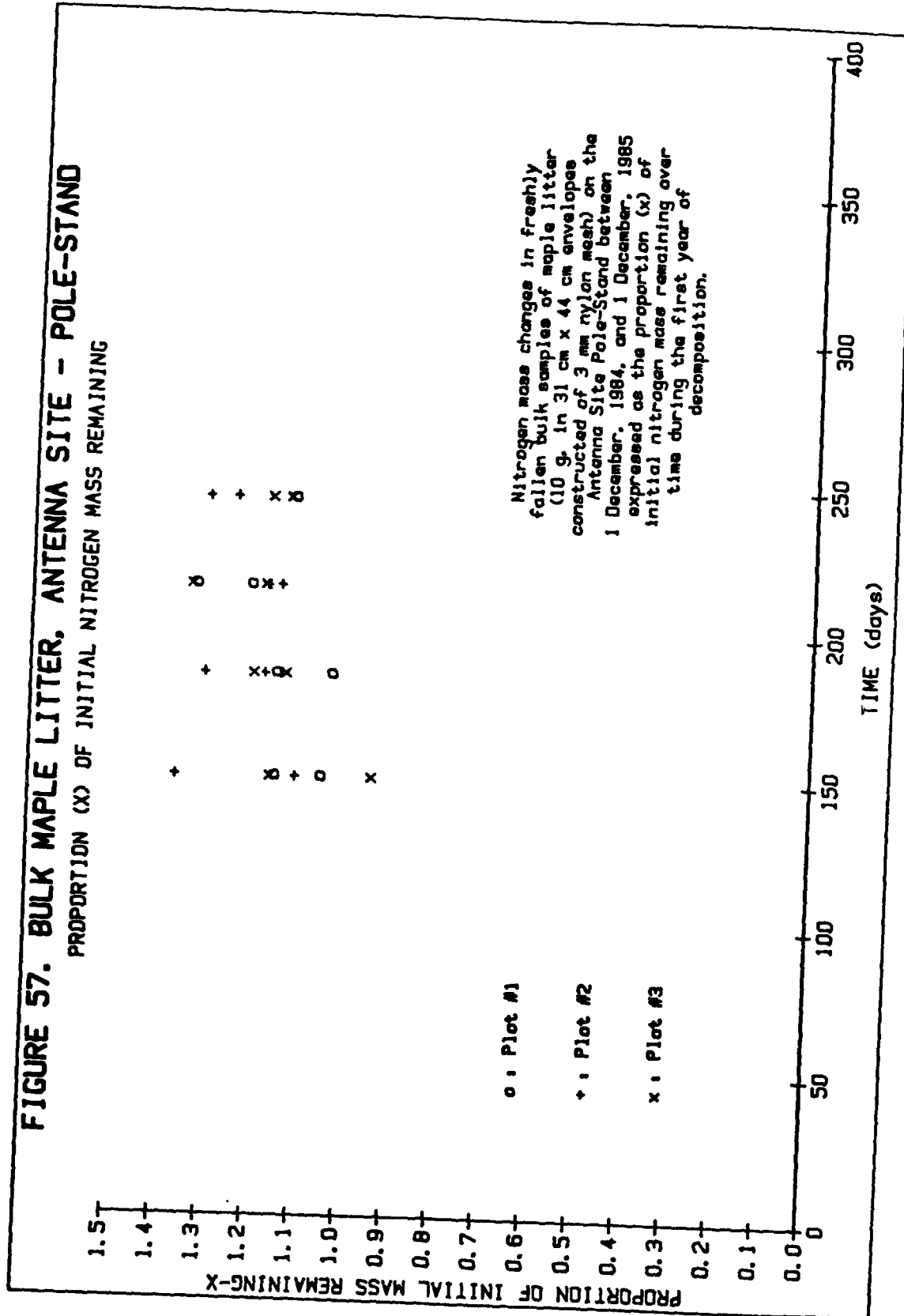
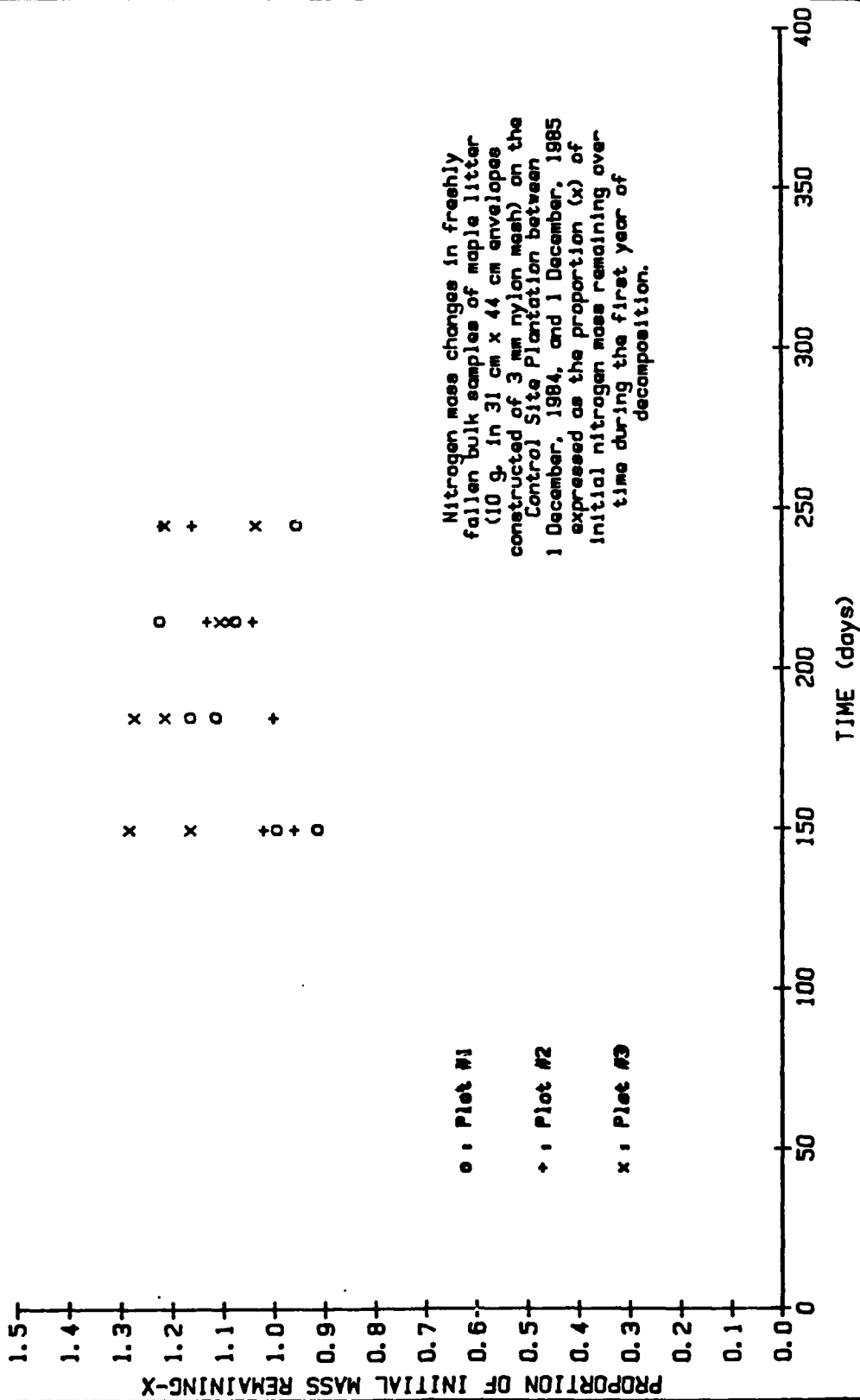
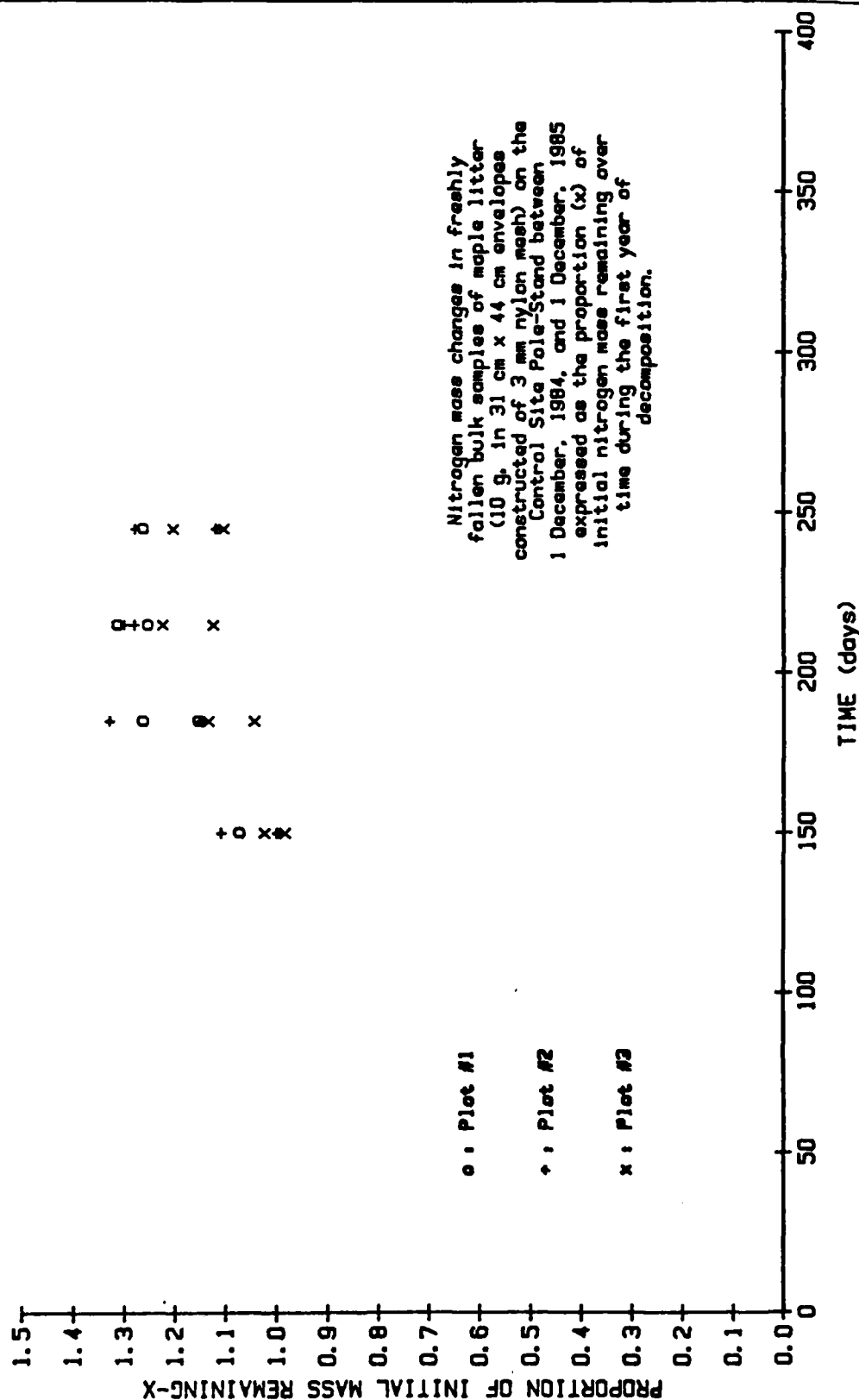


FIGURE 58. BULK MAPLE LITTER, CONTROL SITE - PLANTATION

PROPORTION (X) OF INITIAL NITROGEN MASS REMAINING



**FIGURE 59. BULK MAPLE LITTER, CONTROL SITE - POLE-STAND**  
 PROPORTION (X) OF INITIAL NITROGEN MASS REMAINING



August, 1985, pine litter nitrogen content was not significantly different (at the Ground site plantation or at either the Antenna site plantation or pole-stand) from the values obtained in 1984. Tables 18 through 20 and figures 60 through 73 present the phosphorus flux data available to date. While no statistical analysis has yet been performed on these data, it appears that 1984-85 bulk pine samples from the Antenna and Ground sites (especially in the Antenna site pole-stand) maintained their initial P content more effectively than did comparable samples from the 1983-84 study. Additional between-year comparisons will be made once the complete data set becomes available. In addition, the relationships between nutrient flux and total mass loss, precipitation, air temperature, and litterfall will be investigated via correlation analysis.

Table 21 presents a summary of mean daily temperature ( $^{\circ}\text{C}$ ) over the intervals between litter sample retrieval for each of the three plantations and two pole-stands. Figure 74 presents precipitation data for the same intervals at the three study sites, compiled both as the number of days during each interval with at least 0.01 inch of rain and as total precipitation during each interval. Table 22 presents partial correlation coefficients characterizing the relationships between mass loss and mean air temperature, precipitation, and frequency of precipitation events. Of primary interest is the significant inverse relationship between air temperature and precipitation. In 1985, the study sites were generally characterized by 1) a cool, moist spring and late summer, 2) a warmer, drier mid-summer, and 3) a cool, dry autumn. Pine litter decomposition showed the strongest correlations, both with air temperature and precipitation and during both the current and immediately previous intervals. Oak litter mass loss was well correlated with precipitation, but not with air temperature. Maple litter mass loss was relatively poorly correlated with precipitation and showed no apparent correlation with air temperature. None of the three litter species was significantly correlated with frequency of precipitation events. The apparent importance of weather during the previous

Table 18. Mean proportions<sup>a</sup> of initial total P content remaining at different times in 1985, for bulk red pine foliar litter samples disbursed in early December, 1984.

Sample Retrieval Date	Ground Site Plantation	Antenna Site	
		Plantation	Pole-stand
30 April	1.00 (0.06) <sup>b</sup>	1.13 (0.02)	1.13 (0.13)
2 June	0.91 (0.08)	1.09 (0.05)	1.09 (0.07)
3 July	0.97 (0.09)	0.97 (0.06)	1.16 (0.11)
31 July	0.94 (0.07)	0.98 (0.07)	1.20 (0.15)
27 August <sup>c</sup>			
31 October <sup>c</sup>			
2 November <sup>c</sup>			
1 December <sup>c</sup>			

Table 18. (cont)

Sample Retrieval Date	Control Site	
	Plantation	Pole-stand
30 April	1.26 (0.07)	0.97 (0.11)
2 June	1.09 (0.10)	0.93 (0.17)
3 July	1.03 (0.03)	0.96 (0.07)
31 July	1.09 (0.11)	0.99 (0.14)
27 August <sup>c</sup>		
31 October <sup>c</sup>		
2 November <sup>c</sup>		
1 December <sup>c</sup>		

<sup>a</sup>/ Proportion ( $X=W_1/W_0$ ), where  $W_0$  and  $W_1$  are the percentages of P (w/w, 30°C) multiplied by total dry weight (30°C) for time 0 and time 1, respectively.

<sup>b</sup>/ standard deviation

<sup>c</sup>/ These data are not yet available.

Table 19. Mean proportions<sup>a</sup> of initial total P content remaining at different times in 1985, for bulk northern red oak foliar litter samples disburied in early December, 1984.

Sample Retrieval Date	Ground Site Plantation	Antenna Site	
		Plantation	Pole-stand
30 April	0.57 (0.09) <sup>b</sup>	0.54 (0.11)	0.79 (0.07)
2 June	0.58 (0.08)	0.58 (0.17)	0.78 (0.06)
3 July	0.58 (0.04)	0.61 (0.17)	0.78 (0.12)
31 July	0.71 (0.08)	0.57 (0.07)	0.72 (0.08)
27 August <sup>c</sup>			
31 October <sup>c</sup>			
2 November <sup>c</sup>			
1 December <sup>c</sup>			

Table 19. (cont)

Sample Retrieval Date	Control Site	
	Plantation	Pole-stand
30 April	0.69 (0.06)	0.79 (0.04)
2 June	0.62 (0.06)	0.75 (0.07)
3 July	0.58 (0.04)	0.76 (0.06)
31 July	0.63 (0.02)	0.73 (0.04)
27 August <sup>c</sup>		
31 October <sup>c</sup>		
2 November <sup>c</sup>		
1 December <sup>c</sup>		

a/ Proportion ( $X=W_1/W_0$ ), where  $W_0$  and  $W_1$  are the percentages of P (w/w, 30°C) multiplied by total dry weight (30°C) for time 0 and time 1, respectively.

b/ standard deviation

c/ These data are not yet available.

Table 20. Mean proportions<sup>a</sup> of initial total P content remaining at different times in 1985, for bulk red maple foliar litter samples disbursed in early December, 1984.

Sample Retrieval Date	Ground Site Plantation	Antenna Site	
		Plantation	Pole-stand
30 April	0.48 (0.05) <sup>b</sup>	0.51 (0.10)	0.73 (0.09)
2 June	0.47 (0.06)	0.56 (0.07)	0.70 (0.06)
3 July	0.50 (0.04)	0.51 (0.06)	0.69 (0.07)
31 July	0.51 (0.02)	0.51 (0.07)	0.68 (0.06)
27 August <sup>c</sup>			
31 October <sup>c</sup>			
2 November <sup>c</sup>			
1 December <sup>c</sup>			

Table 20. (cont)

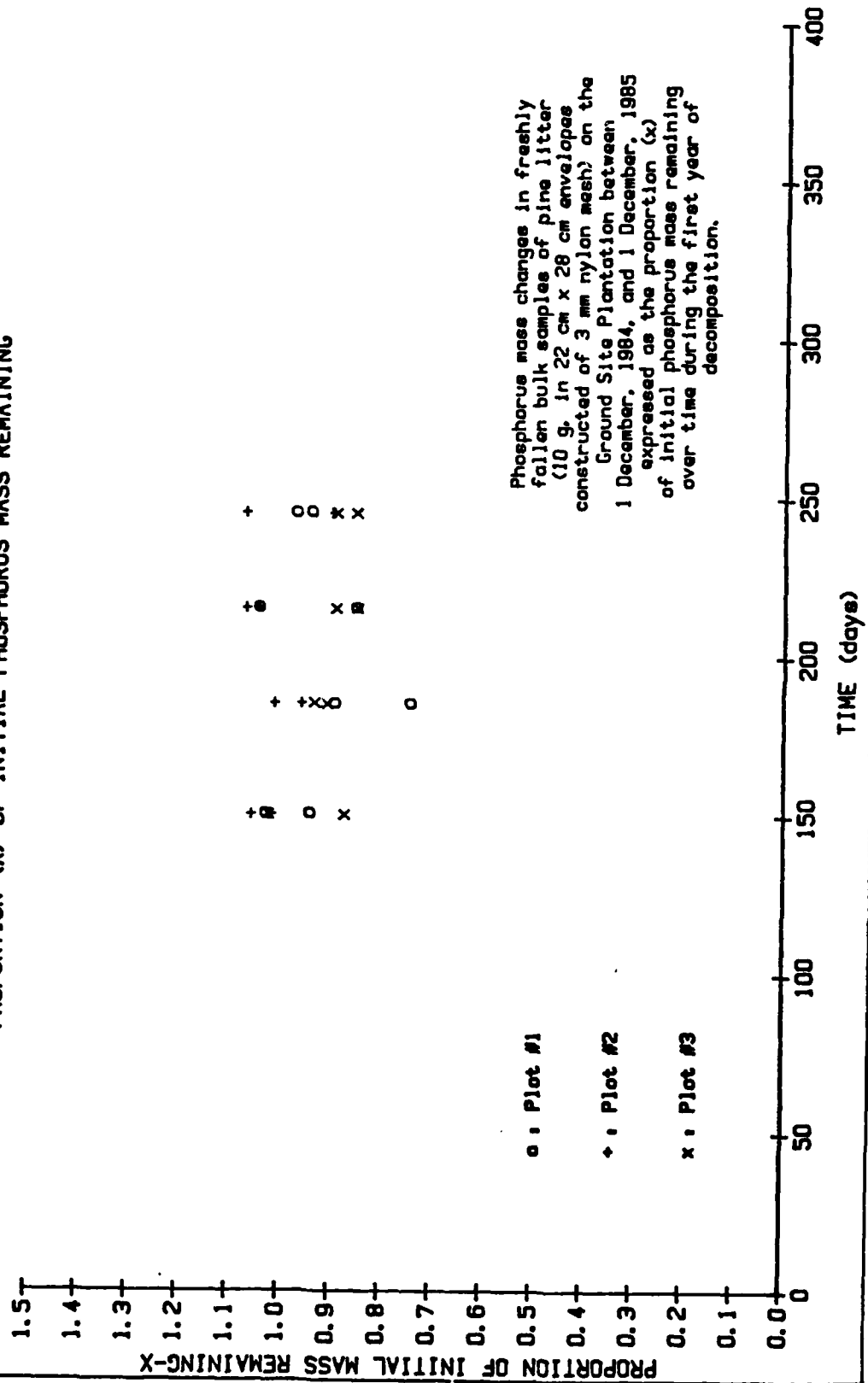
Sample Retrieval Date	Control Site	
	Plantation	Pole-stand
30 April	0.67 (0.14)	0.76 (0.05)
2 June	0.66 (0.11)	0.75 (0.10)
3 July	0.55 (0.04)	0.81 (0.08)
31 July	0.59 (0.06)	0.78 (0.07)
27 August <sup>c</sup>		
31 October <sup>c</sup>		
2 November <sup>c</sup>		
1 December <sup>c</sup>		

a/ Proportion ( $X=W_1/W_0$ ), where  $W_0$  and  $W_1$  are the percentages of P (w/w, 30°C) multiplied by total dry weight (30°C) for time 0 and time 1, respectively.

b/ standard deviation

c/ These data are not yet available.

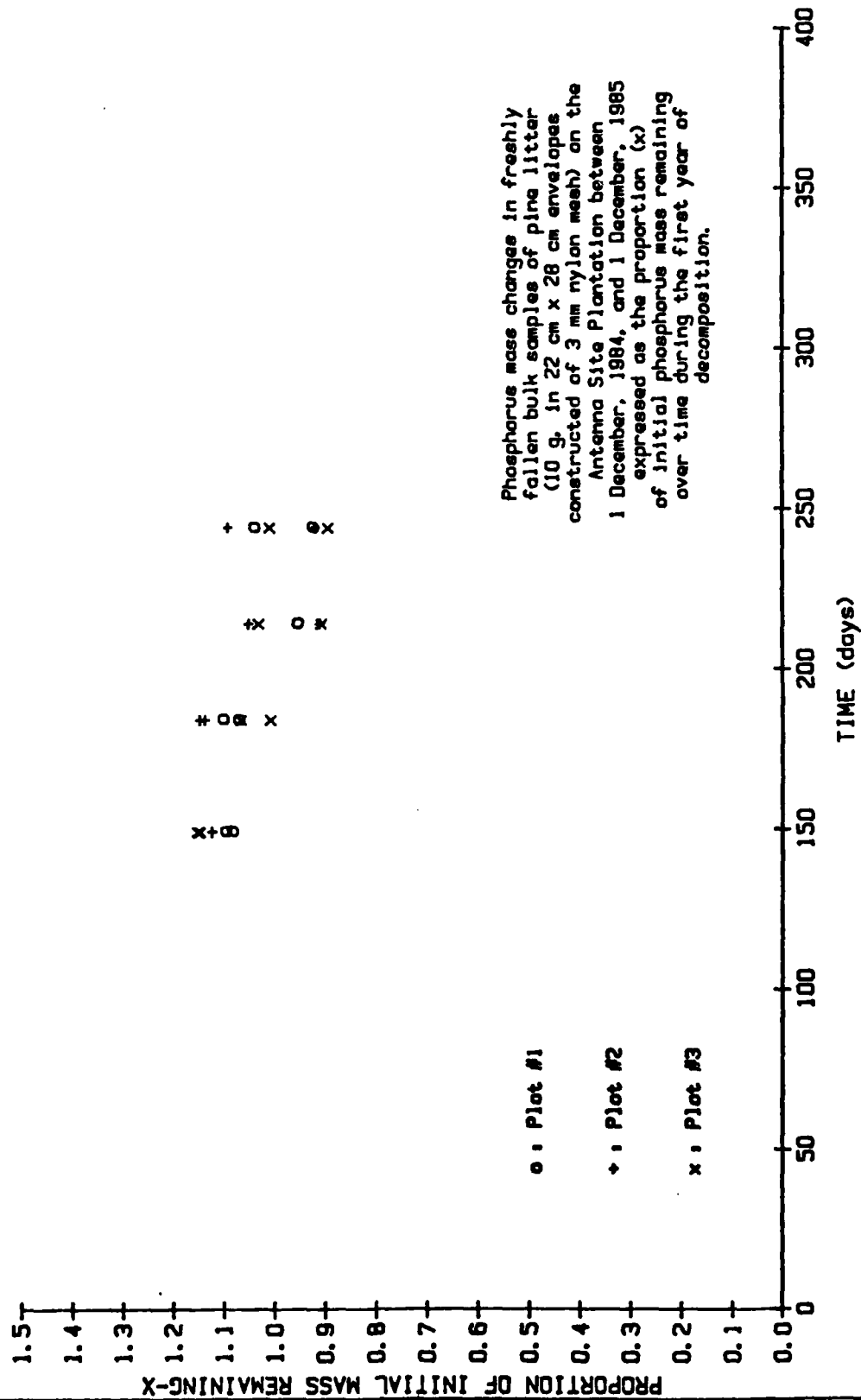
**FIGURE 60. BULK PINE LITTER, GROUND SITE - PLANTATION**  
 PROPORTION (X) OF INITIAL PHOSPHORUS MASS REMAINING



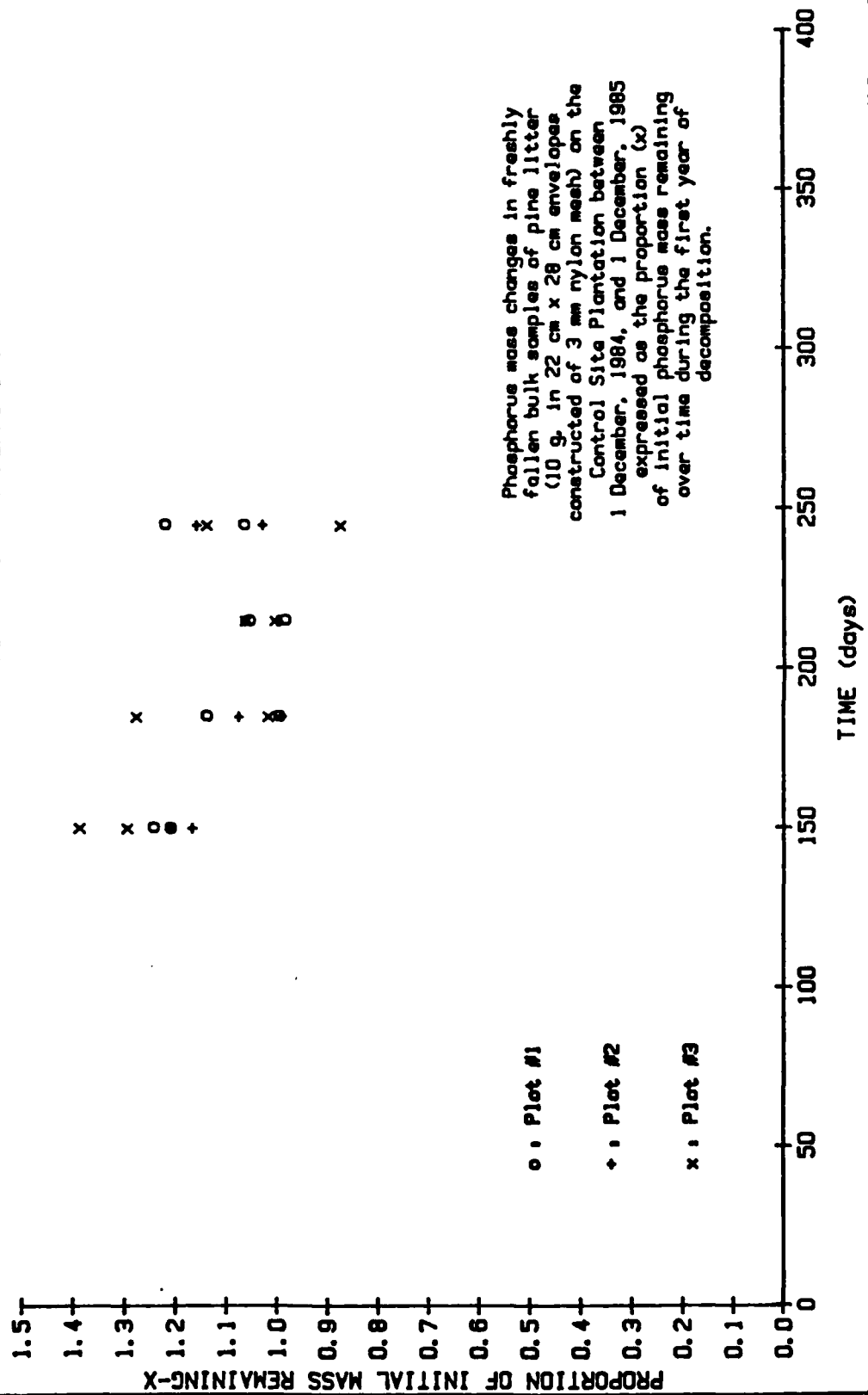


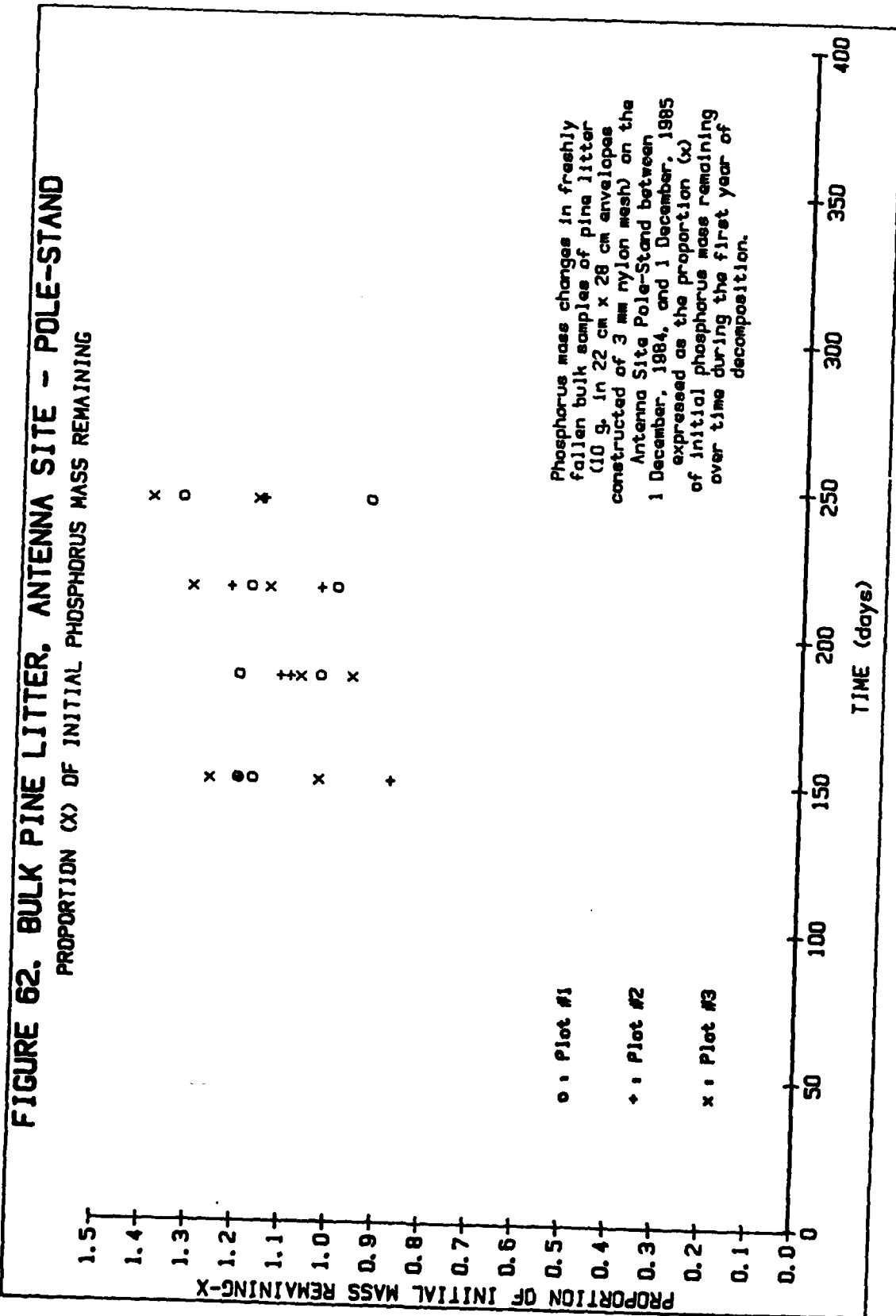
**FIGURE 61. BULK PINE LITTER, ANTENNA SITE - PLANTATION**

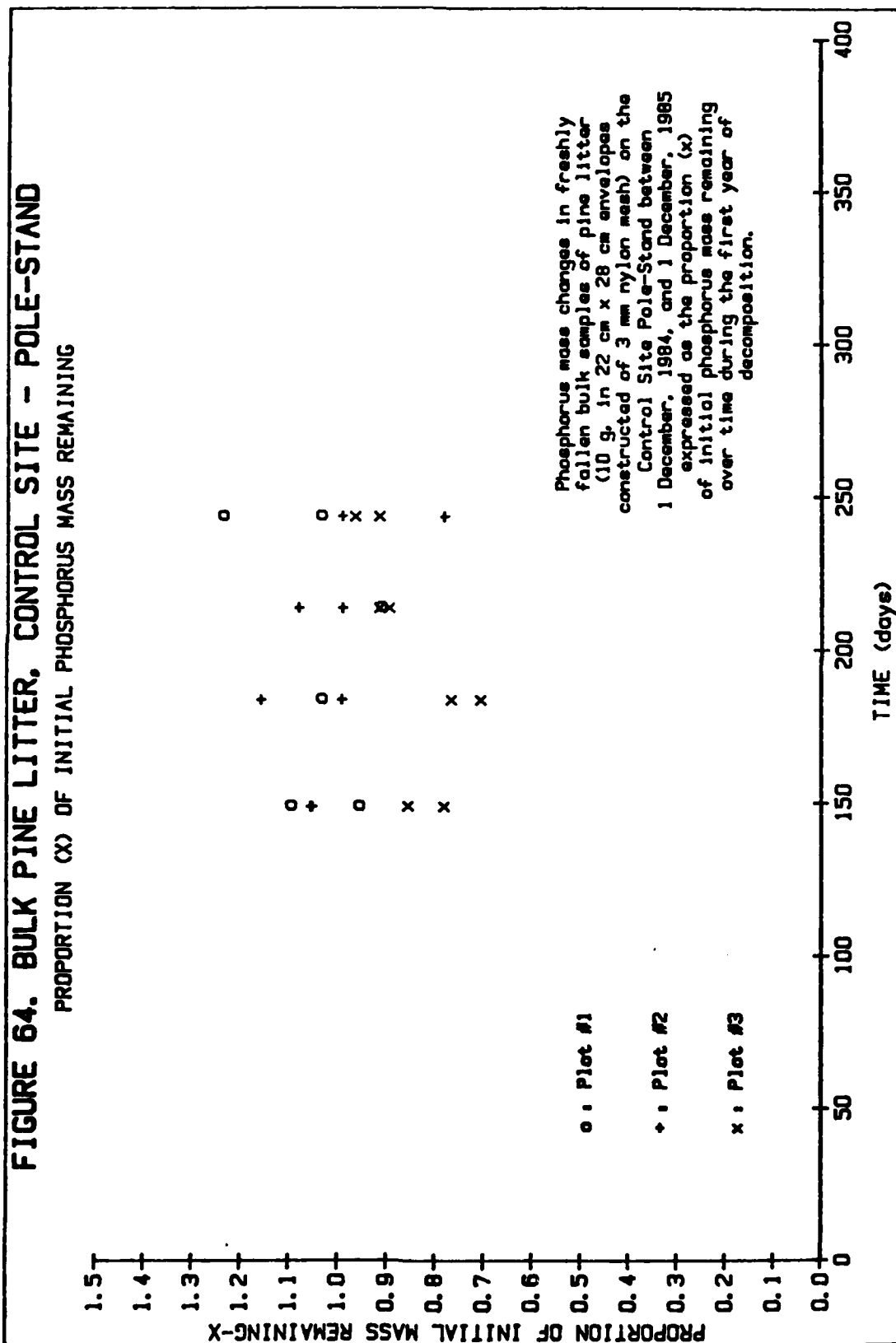
PROPORTION (X) OF INITIAL PHOSPHORUS MASS REMAINING

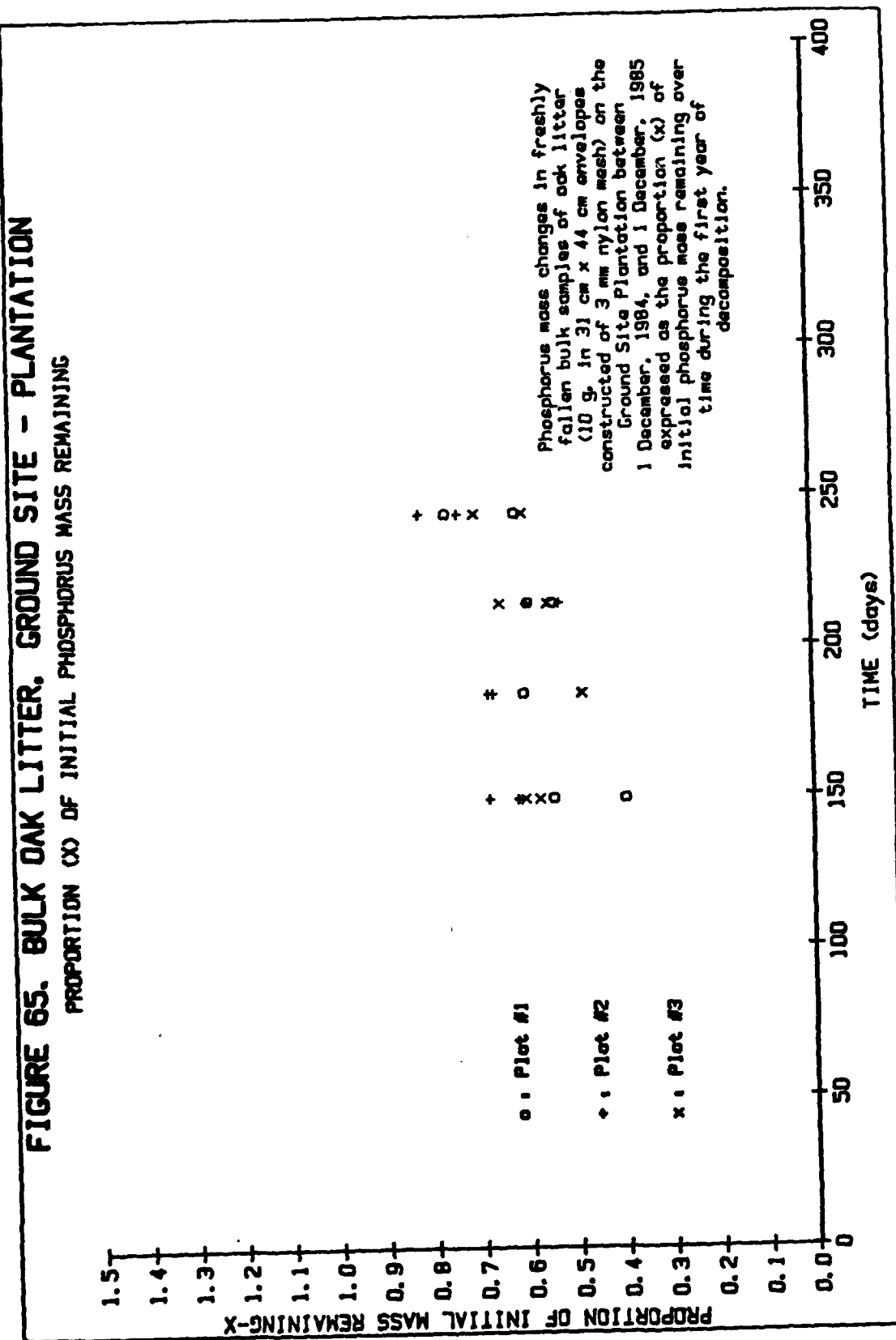


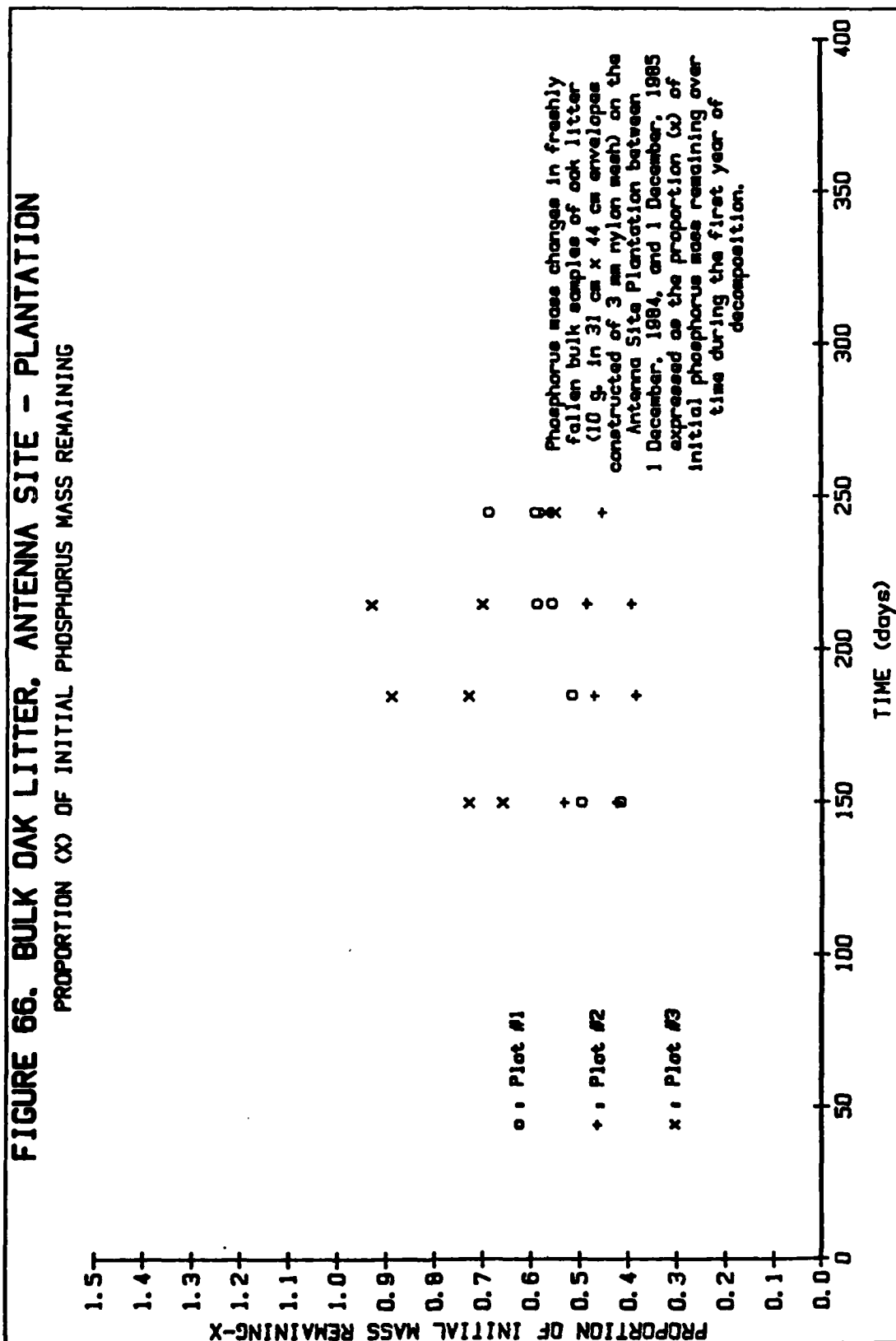
**FIGURE 63. BULK PINE LITTER, CONTROL SITE - PLANTATION**  
PROPORTION (X) OF INITIAL PHOSPHORUS MASS REMAINING



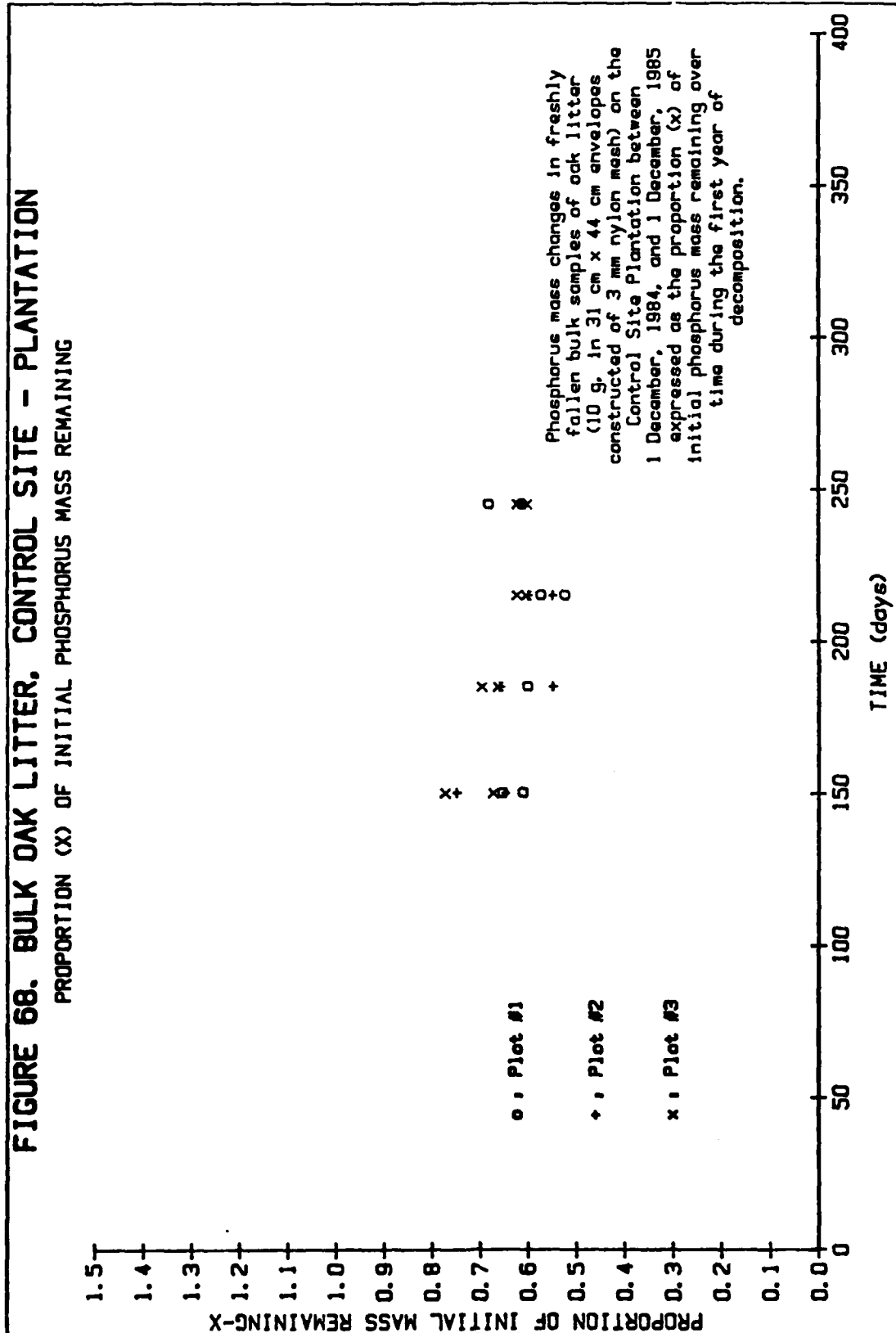




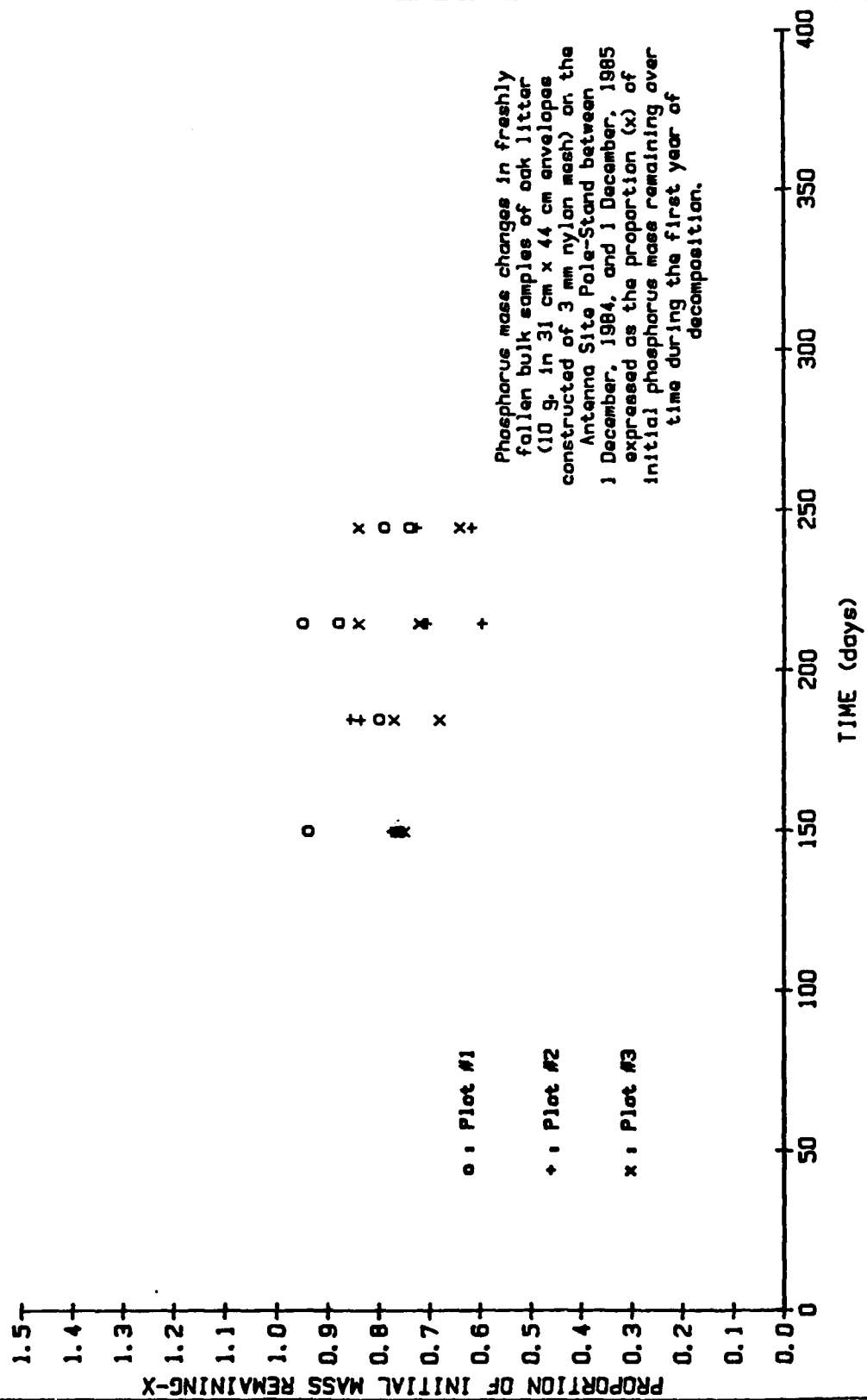




**FIGURE 68. BULK OAK LITTER, CONTROL SITE - PLANTATION**  
PROPORTION (X) OF INITIAL PHOSPHORUS MASS REMAINING

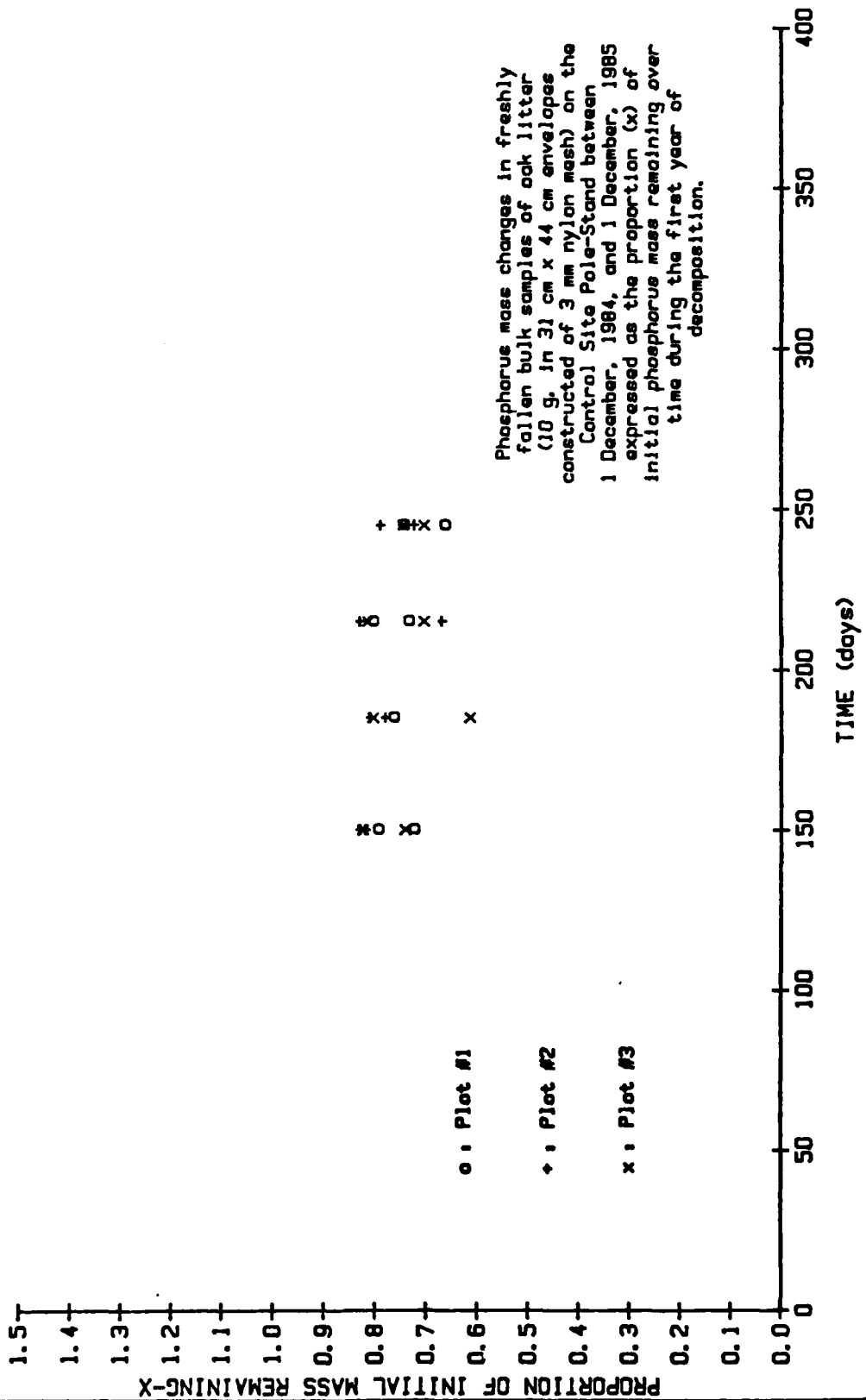


**FIGURE 67. BULK OAK LITTER, ANTENNA SITE - POLE-STAND**  
**PROPORTION (X) OF INITIAL PHOSPHORUS MASS REMAINING**





**FIGURE 69. BULK OAK LITTER, CONTROL SITE - POLE-STAND**  
**PROPORTION (X) OF INITIAL PHOSPHORUS MASS REMAINING**



**FIGURE 70. BULK MAPLE LITTER, GROUND SITE - PLANTATION**  
**PROPORTION (X) OF INITIAL PHOSPHORUS MASS REMAINING**

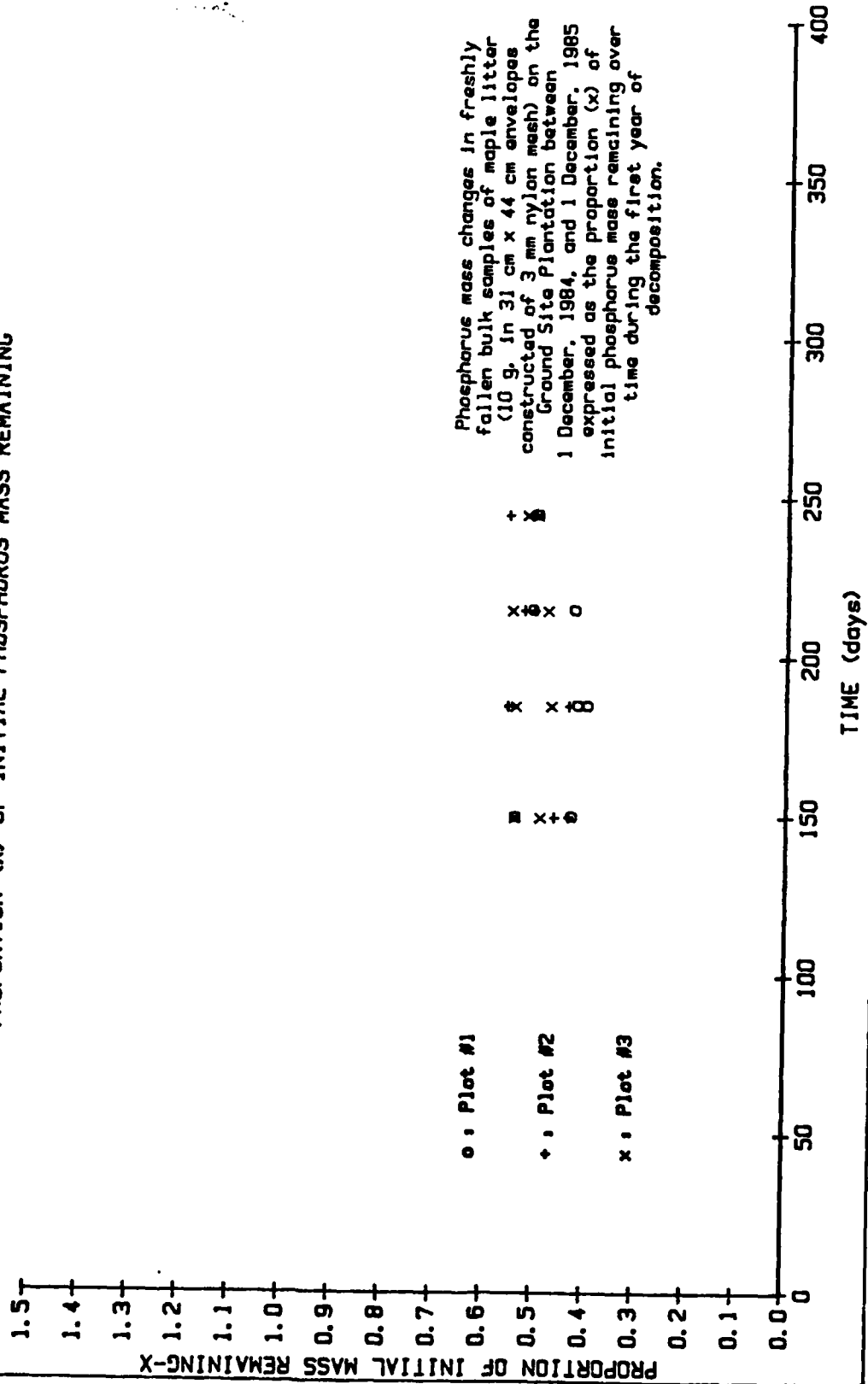


FIGURE 71. BULK MAPLE LITTER, ANTENNA SITE - PLANTATION

PROPORTION (X) OF INITIAL PHOSPHORUS MASS REMAINING

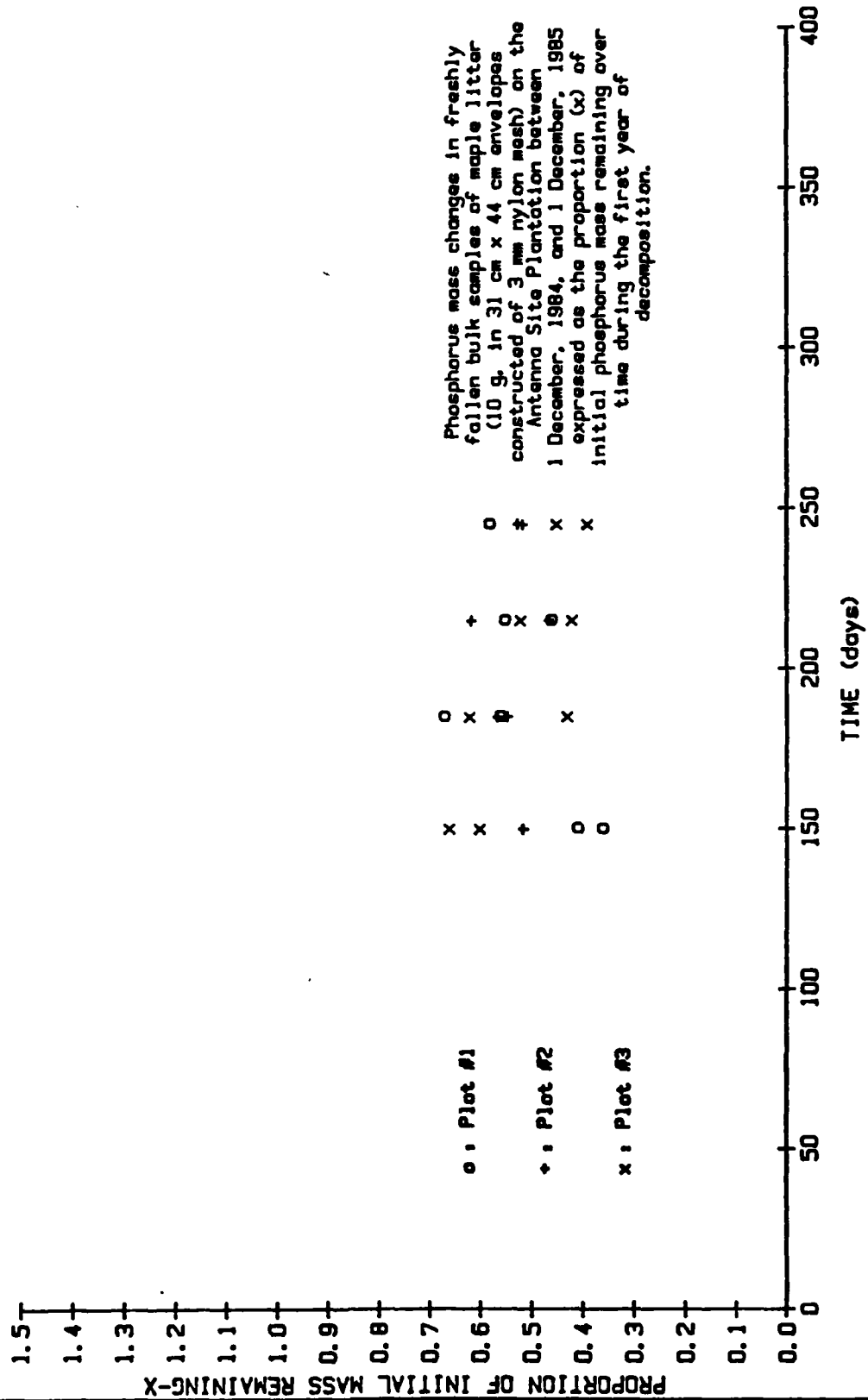
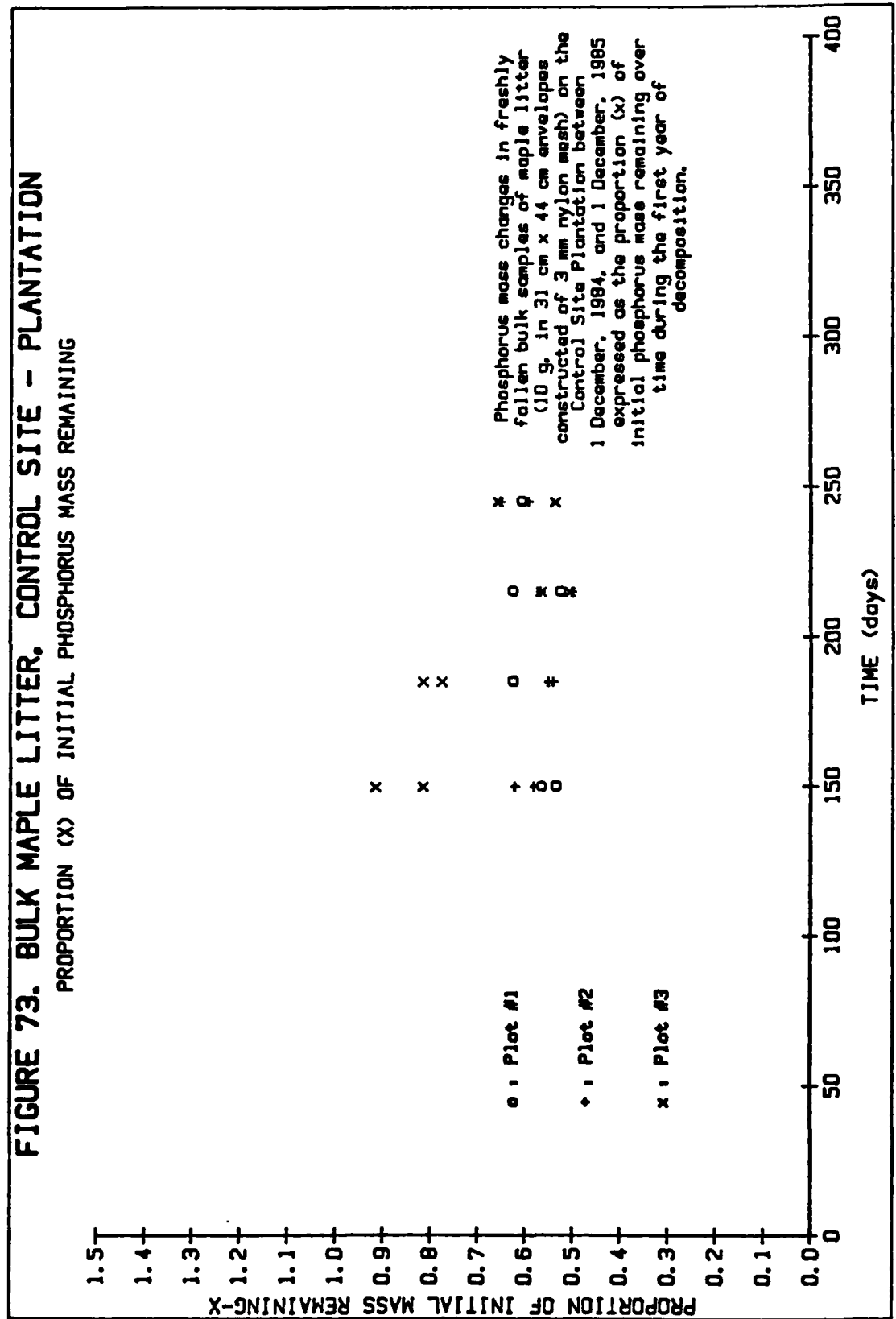


FIGURE 73. BULK MAPLE LITTER, CONTROL SITE - PLANTATION

PROPORTION (X) OF INITIAL PHOSPHORUS MASS REMAINING



**FIGURE 72. BULK MAPLE LITTER, ANTENNA SITE - POLE-STAND**  
**PROPORTION (X) OF INITIAL PHOSPHORUS MASS REMAINING**

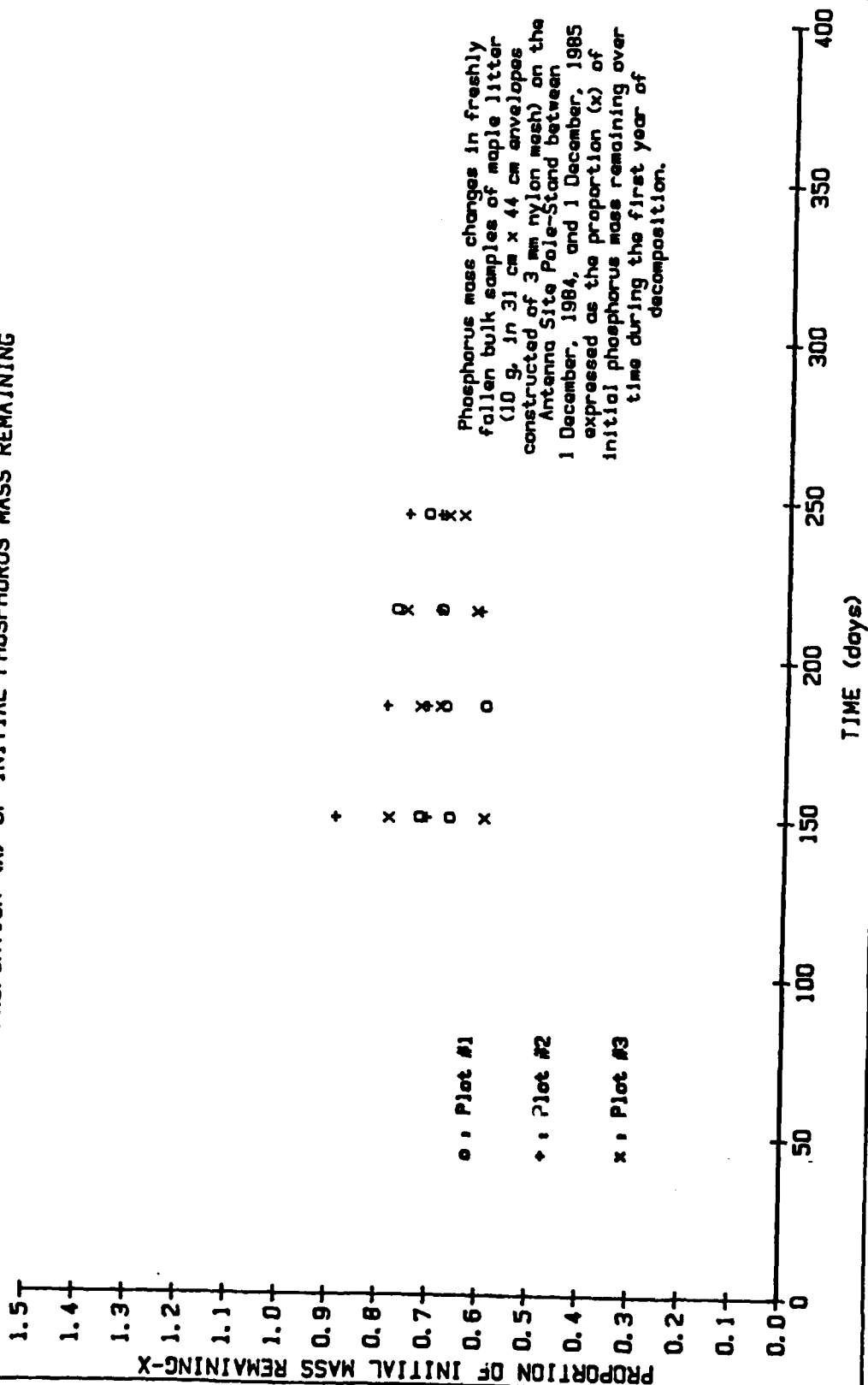


FIGURE 73. BULK MAPLE LITTER, CONTROL SITE - POLE-STAND

PROPORTION (X) OF INITIAL PHOSPHORUS MASS REMAINING

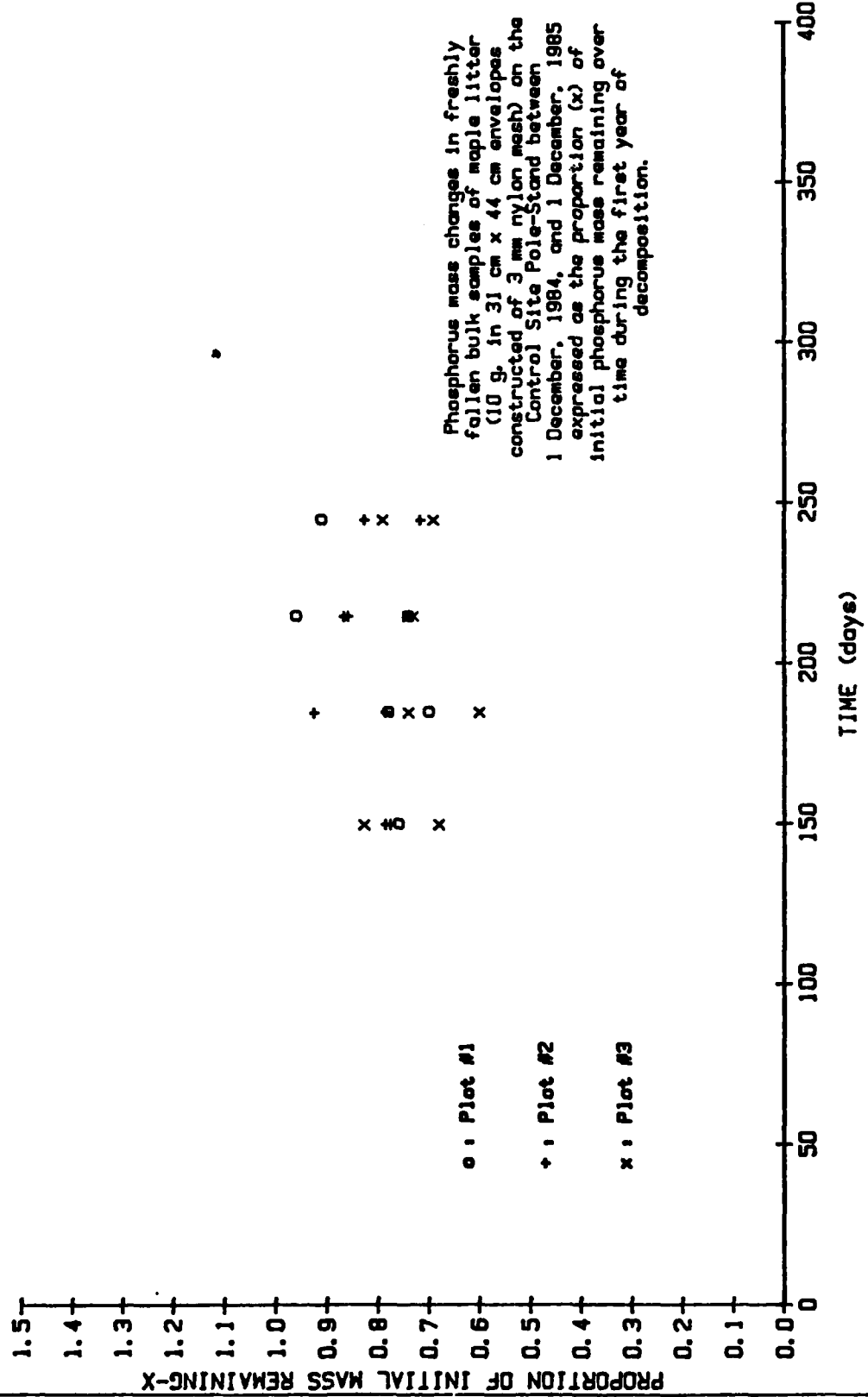


Table 21. Mean daily temperatures (°C)<sup>a</sup> during intervals between retrieval of litter samples.

Interval	Duration (days)	Antenna Site				Ground Site		Control Site			
		Plantation		Pole-Stand		Plantation		Plantation		Pole-Stand	
		Mean	# Obs. <sup>b</sup>	Mean	# Obs.	Mean	# Obs.	Mean	# Obs.	Mean	# Obs.
30 Apr- 1 Jun	33	53.7	26	53.6	26	52.7	30	53.9	34	54.8	33
2 Jun- 1 Jul	30	56.2	30	56.2	30	57.1	14	57.4	30	57.8	30
2 Jul-30 Jul	29	61.7	28	61.7	28	62.4	28	63.2	29	63.8	29
31 Jul-26 Aug	27	60.7	27	60.3	27	57.8	01	60.7	25	61.2	25
27 Aug-12 Oct	47	51.5	47	51.1	47	49.2	38	51.9	47	52.1	47
13 Oct- 1 Nov	20	44.6	20	44.1	20	43.9	20	45.0	20	45.8	20
2 Nov-30 Nov	29	25.0	29	25.0	29	26.0	29	24.3	29	24.3	29

<sup>a</sup>/ based on the plot transmitting the most data for each plantation or pole-stand; when 2 or 3 plots transmitted readings for the maximum number of days, the average of the mean plot temperatures over those days is reported.

<sup>b</sup>/ the number of days for which at least 6 of the 8 possible 3-hour transmissions were received.

Figure 74.

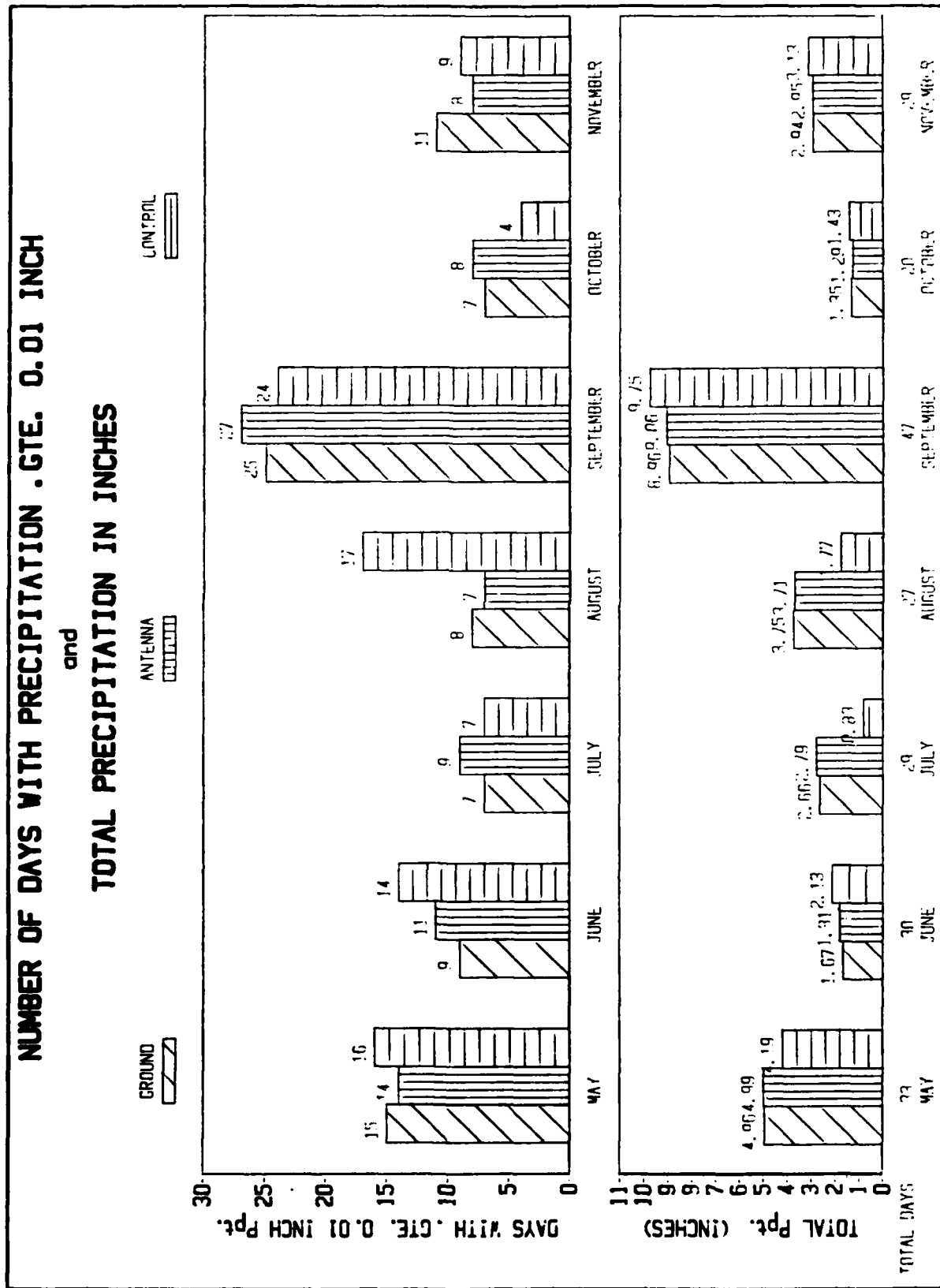




Table 22. Partial correlation coefficients exploring relationships between current month and previous month bulk sample decomposition ( $X$  and  $X_0$ , respectively) and selected environmental parameters of precipitation and air temperature.

Partial Correlation	Pine	Oak	Maple
	$r^1$	$r$	$r$
$XaTb \cdot t^c$	.214*	-.210*	.045
$XT_0^d \cdot t$	.214*	-.210*	.045
$XT \cdot P$	.291**	-.055	.002
$XT_0 \cdot P$	.542***	.181	.114
$XT_0 \cdot P_0$	.543***	-.055	.002
$XT_0 \cdot T$	.525***	.144	.078
$XP^e \cdot t$	.408***	.206	.222*
$XP_0^f \cdot t$	.408***	.206	.222*
$XP_0 \cdot P$	.610***	.398***	.172
$XP \cdot T$	.466***	.352**	.203
$XP_0 \cdot T$	.601***	.340**	.133
$XP_0 \cdot T_0$	.466***	.352**	.203
$XP \cdot E$	.590***	.361***	.184
$XE^g \cdot t$	-.020	-.058	.137
$XX_0^h \cdot t$	.276**	.137	.334**
$PT \cdot t$	-.287**	-.287**	-.287**

a/ change in mass during a given interval between two sample collection dates.

b/ the mean air temperature ( $^{\circ}C$ ) during the given interval being considered multiplied by the number of days in that interval.

c/ the length of the given interval being considered, in days.

d/ the air temperature index described in b/ for the previous sampling interval.

e/ the mean daily precipitation received during the interval being considered.

f/ the mean daily precipitation received during the previous sampling interval.

g/ the proportion of days during the interval being considered with measurable precipitation ( $> 0.01$  in).

h/ change in mass during the previous sampling interval.

i/ \* indicates significance of  $P \leq 0.05$ ; \*\* indicates significance of  $P \leq 0.01$ ; \*\*\* indicates significance of  $P \leq 0.001$ .

interval suggests the existence of considerable inertia (Jansson and Berg 1985), probably in response to the dynamics of decomposer population activities.

Element 2: Rhizoplane and Rhizosphere Actinomycetes

Introduction

In the past year (1985), the emphasis of this element has been on the enumeration and characterization of streptomycetes associated with the red pine mycorrhizal rhizoplane (i.e., washed mycorrhizal roots) and the isolation and characterization of streptomycetes specifically associated with short segments of mycorrhizal root tips. The mycorrhizal condition of red pine seedlings in the Antenna, Ground, and Control site plantations has been followed on a monthly basis in 1985, from May through October, by staff of the Herbaceous Plant Cover and Tree Studies. Samples of the red pine mycorrhizae collected and identified from each of the ELF study red pine plantations were provided to this study for analysis of streptomycete population dynamics. Triplicate washed root samples (for macerate plate counts) and samples of 25 root tips (for enrichment isolation) representing distinct mycorrhizal types recovered from each of the three ELF study red pine plantations were analyzed in order to increase the statistical value of the resulting streptomycete data. The enrichment technique developed during 1984 was used to recover streptomycetes associated specifically with individual washed mycorrhizal root tips ( $\leq 2$  mm sections). The intent of adding the latter analysis was to provide data on even more specific streptomycete/mycorrhizae interactions to complement the washed fine root studies, as this type of relationship is expected to be fairly stable with time.

One additional test was also used during this time period, to briefly evaluate the possible relationships between root-associated streptomycetes and mycorrhizae. Pure cultures of streptomycetes from some of the ELF sites were assayed for their potential to inhibit or promote the growth of three isolates of Laccaria spp., a genus of mycorrhizal fungi known to be associated with the red pine at the ELF plantation sites.

The data obtained during the 1985 sampling season were also compared to the limited data on streptomycetes associated with

specific mycorrhizal root types obtained in 1984, in particular from the same sites over the same time period, to begin assessment of the stability of the red pine-associated rhizoplane streptomycete populations between and within sites.

#### Methods

Red pine washed root and mycorrhizal root tip samples were collected and prepared monthly from late May to late October by team researchers in the MTU Department of Forestry Forest Microbiology lab and delivered to the Environmental Microbiology lab in the Department of Biological Sciences in sterile containers. These samples were usually processed within 24-48 hours of receipt. Samples were designated as to collection site, i.e., Antenna (AS), Ground (GS) or Control (CS). Triplicate samples were analyzed for each site, consisting of one composite sample per plantation study plot representing a mixture of roots from all red pine collected for that date.

Using flame-sterilized forceps, 0.1 g (wet weight) of washed roots was placed in 9.9 ml sterile buffer (0.01 M phosphate buffer, pH 7.2) and homogenized in a flame-sterilized 30 ml blender. This mixture was then transferred to a sterile, screw-cap test tube. Subsequent serial dilutions were made using the same type of sterile buffer. A larger portion of the washed roots (about 0.5 g) was transferred to a pre-weighed aluminum pan and weighed; this portion was then placed in a drying oven for determination of dry weight.

As in the earlier studies, all washed root samples (after preparation and appropriate serial dilution) were spread-plated onto starch casein agar (SCA) in 100 x 15 mm petri dishes. Cycloheximide (50 mg/l) and nystatin (50 mg/l) were added to the SCA to prevent fungal growth (Andrews and Kennerly 1979, Goodfellow and Dawson 1978). At least three dilutions (in duplicate) were spread-plated per sample. All plates were incubated at 20°C. Total numbers of streptomycete colonies were determined after 7 and 14 days incubation.

After 14 days incubation, the morphology of individual streptomycete colonies was determined. All colonies with the same characteristics (i.e., presence/absence of diffusible pigment, presence/absence of aerial mycelium, color of aerial mycelium, and reverse colony color) were considered to represent one morphological type or strain (Keast et al. 1984). At least one colony per streptomycete type was isolated in pure culture for further study. Using the format of Shirling and Gottlieb (1966), the streptomycete cultures are being characterized for melanin production, color of aerial mycelia, production and color of reverse and soluble pigments, sporophore structure, and carbohydrate utilization. Additional tests are being conducted to evaluate calcium oxalate (Jayasuriya 1955, Knutson et al. 1980), cellulose, and lignocellulose (Sutherland 1985) degradation. The streptomycete types found in the 1985 samples were compared to those observed in similar samples from 1984, in particular, to determine if some of the same types are present after the red pine seedlings have been in the field one year or more and to determine whether the same types were present at the three ELF study sites.

Enrichment techniques were used for detecting those streptomycetes associated with short (2 mm or less) portions of mycorrhizal fine root tips. Root tip enrichments were conducted by aseptically transferring one mycorrhizal root tip portion to a 25-ml flask containing 5 ml starch casein broth, with sodium propionate (4 g/l, Kutzner 1981) and cycloheximide (50 mg/l) added to reduce bacterial and fungal growth, respectively. The flasks were then heated to 55°C for 6 min before shaking, in order to reduce bacterial levels (Orchard 1984). Some type of preheat treatment is commonly used when working with natural populations of streptomycetes, as their spores in particular can withstand these temperatures (as reviewed in Kutzner 1981; Williams et al. 1972). In studies with pure cultures of streptomycetes and root samples, this heat treatment did not affect detection of streptomycetes, but reduced levels of bacteria and some fungi which would otherwise have outgrown the streptomycetes in the enrich-

ment flasks. Twenty-five root tips were tested per sample per type. The flasks were placed on a floor-model rotary shaker at moderate speed for 48 hrs at 20-22°C. Broth was streaked onto SCA at 24 and 48 hrs. After incubation at 20°C, the plates were examined for streptomycete colonies. All streptomycete colonies were typed using the previously described criteria, transferred to fresh SCA to obtain pure cultures, and saved for characterization studies.

An additional study was conducted during the 1985 season to assess whether or not the streptomycetes associated with the mycorrhizae have an antagonistic or protagonistic effect on the fungi. Using a modification of the technique described by Rosenzeig and Stotsky (1979), pure cultures of streptomycetes from both the root tip enrichments and the washed root samples were spotted onto the center of 9 cm diameter petri dishes containing Modified Melin Norkrans (MMN) agar medium (Molina and Palmer 1982). After 72-96 hours growth at 25° C, pure cultures of three Laccaria spp. isolates were inoculated onto the MMN plates 1.0 cm from the margin of each developing streptomycete colony. The MMN plates were examined twice weekly to determine whether or not the streptomycete inoculant had produced a diffusible substance capable of affecting growth of the mycorrhizal fungus inoculant. Final measurements were made 19 days following fungus inoculation, and consist of radial growth away from the streptomycete inoculum. Triplicate petri plates representing each streptomycete/fungus combination were included.

Data for streptomycete levels and types based on the SCA plate counts were transformed to  $\log_{10}$  (Orchard 1984) and evaluated statistically using a two-way analysis of variance (SPSS ANOVA) to compare sampling dates and sampling sites at the  $\alpha = 0.05$  significance level (Zar 1984). Where the analyses showed significant differences between sites or among sampling dates, Tukey's w procedure was used to conduct multiple comparisons between sites and/or sampling dates (Steel and Torrie 1980).

#### Description of Progress

Only red pine washed mycorrhizal roots and mycorrhizal fine root tips were analyzed for presence of streptomycetes during the 1985 sampling season. Samples were collected monthly from May through October from each of the Control (CS), Antenna (AS) and Ground (GS) ELF study sites, with triplicate samples of washed roots or root tips examined per site (i.e., one composite sample from each of the three study plots at each plantation site). The same sites were sampled in 1985 as in 1984, in order to also follow potential changes or patterns in streptomycete levels and types associated with red pine nursery seedlings planted on the sites in June, 1984. Information regarding the mycorrhizal condition of the 1985 red pine seedling samples used in this study is available on pages 162-168 of Annual Report 1985 for the Herbaceous Plant Cover and Tree Studies project.

Data for streptomycete levels and types (reported as mean  $\pm$  S.D. of triplicate samples per site) associated with washed red pine roots of mycorrhizal type 3 from each ELF site are presented in Table 23. This mycorrhizal root type was found on red pines from all sampling sites throughout the sampling season. Mycorrhizal root type 6 was detected only twice, i.e., from one GS sample in July and from all three CS samples in September. Type 3 roots were also detected from all sites and most dates sampled in 1984; type 6 roots were detected on only two sampling dates in 1984 (AS in August and CS in October).

Significant differences in levels of streptomycetes were found both between sampling sites ( $P = 0.002$ ) and sampling dates ( $P = 0.001$ ) for the type 3 mycorrhizal washed roots. Table 25 presents the relevant Two-way ANOVA table. There was no difference in levels of isolated streptomycetes between the AS and GS samples, but the CS samples had significantly lower streptomycete levels than did the AS and GS samples ( $\alpha = .05$ ). Comparisons between sampling dates indicated that the streptomycete levels in the October washed root samples were lower than those from May, July, and August ( $\alpha = .05$ ). In contrast, the highest values for all sites were generally reported in May.

Table 23. Streptomycetes associated with washed mycorrhizal type 3 roots from red pines.

Sampling Date	Sampling Site					
	Control		Antenna		Ground	
	Streptomycetes <sup>a</sup>	No. of Types <sup>a</sup>	Streptomycetes <sup>a</sup>	No. of Types <sup>a</sup>	Streptomycetes <sup>a</sup>	No. of Types <sup>a</sup>
21 May 1985	4.5±2.8x10 <sup>5</sup>	6.7±0.6	4.5±1.6x10 <sup>5</sup>	7.3±0.6	3.9±2.2x10 <sup>5</sup>	7.0±1.0
17 June 1985	9.1±3.1x10 <sup>4</sup>	5.0±1.4	5.2±2.8x10 <sup>5</sup>	6.0±2.0	2.6±1.2x10 <sup>5</sup>	6.0±0.0
16 July 1985	1.7±0.9x10 <sup>5</sup>	4.3±0.6	4.5±0.3x10 <sup>5</sup>	6.3±0.6	4.2±3.0x10 <sup>5</sup>	5.0±1.0
21 Aug. 1985	N.A.	N.A.	2.7±1.2x10 <sup>5</sup>	6.3±0.6	4.7±2.4x10 <sup>5</sup>	5.5±0.7
25 Sept. 1985	1.4±0.7x10 <sup>5</sup>	5.3±1.2	4.5±2.3x10 <sup>5</sup>	4.7±2.1	3.5±3.3x10 <sup>5</sup>	6.3±1.2
23 Oct. 1985	1.0±0.5x10 <sup>5</sup>	4.0±1.0	1.5±0.7x10 <sup>5</sup>	4.3±1.5	9.3±1.3x10 <sup>4</sup>	4.0±1.7

<sup>a</sup> Viable count reported as mean ± standard deviation for 1 g dry weight (triplicate samples).

<sup>b</sup> N.A. - Data not available due to contamination of sample.

Table 24. Isolation of streptomycetes from mycorrhizal fine root tip enrichments.

Sampling Date (1985)	Root Type	Sampling Site					
		Control		Antenna		Ground	
		Isolations <sup>a</sup>	No. of Types <sup>a</sup>	Isolations <sup>a</sup>	No. of Types <sup>a</sup>	Isolations <sup>a</sup>	No. of Types <sup>a</sup>
21 May	3	1.7±1.5	1.0±1.0	0.7±0.6	0.7±0.6	1.0±1.0	0.7±0.6
17 June	3	1.0±1.0	1.0±1.0	0.7±0.6	0.7±0.6	1.7±1.2	1.0±0.0
16 July	3 6	0.7±0.6 N.D. <sup>b</sup>	0.7±0.6	1.0±1.0 N.D.	1.0±1.0	1.0±0.0 2.0 <sup>c</sup>	1.0±0.0 1.0 <sup>c</sup>
21 Aug.	3	1.3±1.5	1.0±1.0	0.7±1.2	0.7±1.2	0.7±0.6	0.7±0.6
25 Sept.	3	1.3±1.5	1.0±1.0	1.0±1.0	1.0±1.0	0.7±0.6	0.7±0.6
23 Oct.	3 6	1.7±0.6 1.7±1.2 <sup>c</sup>	1.0±0.0 1.0±1.0 <sup>c</sup>	1.0±0.0 N.D.	0.7±0.6	1.3±1.5 N.D.	1.0±1.0

<sup>a</sup> Reported as mean ± S.D. for 25 root tip enrichments from triplicate samples.

<sup>b</sup> N.D. - Not detected at this site on this sampling date.

<sup>c</sup> Mycorrhizal root tips of this type were found only at one site on this sampling date.



Table 25. Two-way ANOVA table for analysis of differences in 1985 streptomycete levels detected in association with type 3 mycorrhizal red pine roots between study sites and sampling dates.

Source of Variation	Degrees of Freedom	Mean Square	F	Signif. of F
Main Effects	7	.471	6.189	.000
Site	5	.411	5.405	.001
Date	2	.564	7.417	.002
Two-way Interactions	9	.078	1.025	.441
Site x Date	9	.078	1.025	.441
Explained	16	.250	3.284	.002
Residual	34	.076		
Total	50	.132		

Table 26. Two-way ANOVA table for analysis of differences in 1985 data on numbers of streptomycete types detected in association with type 3 mycorrhizal red pine roots between study sites and sampling dates.

Source of Variation	Degrees of Freedom	Mean Square	F	Signif. of F
Main Effects	7	.038	2.924	.017
Date	5	.051	3.878	.007
Site	2	.004	.336	.717
Two-way Interactions	9	.008	.608	.782
Site x Date	9	.008	.608	.782
Explained	16	.021	1.621	.116
Residual	34	.013		
Total	50	.016		

There were no significant differences in recovery of streptomycete types between sites ( $P = 0.717$ ). Table 26 presents the relevant Two-way ANOVA table. There were significant differences ( $P = 0.007$ ) between sampling dates, however, with the greatest numbers of streptomycete types recovered early in the sampling season (i.e., May and June) and the lowest numbers of types found with the October washed root samples. Only the May vs. October comparison was significant ( $\alpha = .05$ ), however.

These 1985 values (Table 23) are within the range of values detected for streptomycetes levels and types associated with mycorrhizal type 3 washed roots in 1984. No significant differences between sites or dates were found for the 1984 streptomycete level data, in large part because only one or two samples were analyzed per site or date.

Slightly lower levels of streptomycetes and types were detected with the 1985 mycorrhizal type 6 washed roots, i.e.,  $8.5 \times 10^6$  streptomycetes with 3 types from the one GS July sample and  $4.3 \pm 0.4 \times 10^4$  streptomycetes with  $2.0 \pm 1.0$  types from the three CS September samples. These values are similar to those reported for the two type 6 washed root samples examined in 1984.

The enrichment technique data obtained with the type 3 and type 6 mycorrhizal fine root tips are presented in Table 24. As was indicated previously, this technique is being used for the specific purpose of qualitatively detecting streptomycetes and not other soil microorganisms by using the same nutrients as in the plate count technique plus preheat treatment and antibacterial and antifungal inhibitors. Using this technique, streptomycetes were consistently detected from all sites throughout the 1985 sampling season, with only one or two streptomycete types isolated per site. The data from the 1985 enrichment study represent an improvement over the preliminary results obtained in 1984 when fewer samples were examined and no streptomycetes were detected with many of the mycorrhizal root tip samples (including the type 3 root tips). Due to the low numbers of streptomycetes and types recovered, no statistical analyses were conducted on these root tip enrichment data.

Soil temperatures (as measured at 5 and 10 cm depths) probably had little influence on streptomycete levels between sites (Figs. 2.10 and 2.12, on pp. 33 and 34, Annual Report 1985 for the Herbaceous Plant Cover and Tree Studies project). However, lower soil temperatures in October, in general, may be involved in the decline in streptomycete levels and types during that month, as 5 and 10 cm soil temperatures recorded in October were at least 5° C lower than those recorded from May through Septem-

ber. No soil pH measurements were taken during the 1985 sampling season. There were no significant differences in soil moisture content at depths of 5 or 10 cm between the CS and GS plantations during the 1985 field season (Figs. 2.25 and 2.26, on page 48, Annual Report 1985 for the Herbaceous Plant Cover and Tree Studies project). On the other hand, soil moisture content at the CS tended to remain higher throughout the growing season than at the AS, though the difference between the two plantations was significant ( $\alpha = 0.05$ ) only in July (5 and 10 cm) and again in mid-August (5 cm) and early September (10 cm) (Figs. 2.29 and 2.31, on pp. 53 and 54, Annual Report 1985 for the Herbaceous Plant Cover and Tree Studies project). While higher soil moisture content at the CS than at the AS might be expected to help explain the lower streptomycete levels and number of streptomycete types at the AS, there is no apparent similar difference in soil moisture content between the CS and GS to help explain the differences in streptomycete activity between these two sites.

The streptomycete morphological types detected on SCA from both washed roots and root tip enrichments for mycorrhizal root types 3 and 6 are reported in Table 27. The most commonly detected streptomycete type was type B, found as the most numerous streptomycete in two or all of the replicate washed type 3 and 6 root samples from all sites on all dates. Streptomycete types F, O, and T were also routinely detected with the type 3 washed roots at all three sites, at times being very numerous. Streptomycete type O was also found with some of the type 6 washed roots. In addition, types D and L were commonly found with the CS and AS washed type 3 roots. Type C was commonly found with the CS, type M (earlier in the season) was found with the AS, and type E was found with the GS type 3 washed roots.

As with the washed roots, streptomycete morphology type B was isolated from all of the mycorrhizal type 3 and 6 fine root enrichments, i.e., from all sites and dates. For the type 3 enrichments, streptomycete type F was also fairly commonly isolated from the CS, AS, and GS sites. Although fewer streptomycete types were recovered from the mycorrhizal root tip enrich-

Table 27. Streptomycete types associated with mycorrhizal type 3 washed roots and fine root tips.

Sampling Date (1985)	Sampling Site <sup>a</sup>	Sample Type <sup>b</sup>	Streptomycete Type																						
			A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
21 May	CS	WR	X <sup>c</sup>	X <sup>d</sup>	X <sup>c</sup>	X	X	X <sup>c</sup>		X	X	X	X												X
		RT	X	X <sup>c</sup>				X																	
	AS	WR		X <sup>d</sup>	X	X <sup>c</sup>	X <sup>c</sup>	X <sup>c</sup>		X	X <sup>c</sup>	X <sup>c</sup>	X		X <sup>c</sup>		X <sup>d</sup>	X							X
		RT		X <sup>c</sup>								X													
	GS	WR	X <sup>c</sup>	X <sup>d</sup>	X	X		X <sup>c</sup>			X	X <sup>c</sup>	X <sup>c</sup>		X		X <sup>c</sup>	X		X	X	X		X <sup>c</sup>	X
		RT		X <sup>c</sup>																					
17 June	CS	WR		X <sup>d</sup>	X		X			X				X								X			X
		RT		X <sup>c</sup>																	X				
	AS	WR		X <sup>d</sup>			X	X <sup>d</sup>				X		X <sup>c</sup>	X		X				X	X		X <sup>c</sup>	
		RT		X				X																	
	GS	WR		X <sup>d</sup>			X	X <sup>c</sup>	X								X <sup>c</sup>			X <sup>c</sup>		X		X	X
		RT		X <sup>c</sup>			X	X																	
16 July	CS	WR		X <sup>d</sup>	X	X		X											X		X	X			
		RT		X																					
	AS	WR		X <sup>d</sup>			X	X														X		X	
		RT		X																					
	GS	WR		X <sup>d</sup>			X	X																	
		RT		X				X														X		X	
21 August	CS	WR		N.A. <sup>e</sup>				X																	
		RT		X																					
	AS	WR	X <sup>c</sup>	X <sup>d</sup>		X		X				X	X	X <sup>c</sup>			X <sup>c</sup>		X <sup>d</sup>		X	X	X		
		RT		X <sup>c</sup>																					
	GS	WR		X <sup>d</sup>		X		X						X								X <sup>c</sup>	X	X	
		RT		X <sup>c</sup>																		X			
25 September	CS	WR		X <sup>d</sup>		X		X						X			X <sup>c</sup>	X	X			X		X	
		RT		X <sup>c</sup>				X									X								
	AS	WR		X <sup>d</sup>	X									X			X <sup>c</sup>					X	X		X
		RT		X <sup>c</sup>																					
	GS	WR	X	X <sup>d</sup>	X <sup>c</sup>		X	X <sup>d</sup>	X								X <sup>c</sup>	X		X <sup>c</sup>		X		X	X
		RT		X			X																		
23 October	CS	WR		X <sup>d</sup>	X	X								X			X <sup>c</sup>					X			
		RT		X <sup>c</sup>																					
	AS	WR		X <sup>d</sup>				X						X			X	X				X			
		RT		X <sup>c</sup>																					
	GS	WR		X <sup>d</sup>				X <sup>c</sup>				X		X			X <sup>c</sup>	X							
		RT		X <sup>c</sup>				X									X								

<sup>a</sup> CS - Control Site; AS - Antenna Site; GS - Ground Site.

<sup>b</sup> WR - washed roots; RT - root tip enrichments.

<sup>c</sup> Detected in two or more of replicate samples/site.

<sup>d</sup> Predominant type in two or more of replicate samples/site.

<sup>e</sup> N.A. - Data not available due to contamination of sample.

ments than from the washed root plate counts, there was no streptomycete type from the enrichments that was not also associated with the washed roots.

The streptomycetes isolated during the 1985 sampling season were characterized using the format of Shirling and Gottlieb (1968) in order to compare these types to those isolated in the 1983 and 1984 (in particular) studies with red pine mycorrhizal roots. The predominant streptomycete type originally associated with the red pine seedlings in the Toumey Nursery, and present on seedlings at the plantation sites at least through August, 1984, was not found in any of the 1985 washed root or root tip enrichment samples. As was hypothesized in the earlier studies, the nursery environment selected for some streptomycete types not found or able to compete at the outplanting sites.

Data on interactions between streptomycetes isolated from red pines planted at the ELF sites and pure cultures of Laccaria spp. isolates are presented in Table 28. The streptomycete isolates tested had various effects on the test fungi, from inhibition of all three isolates (types P and T from the ELF ground site) to no effect on growth of all three fungal isolates (type F from the ELF ground site). The relevant Two-way ANOVA table is presented as Table 29. Isolate 1PF of L. bicolor demonstrated the fastest growth overall ( $\alpha = .05$ ). Streptomycete isolates GS-B and GS-F had no overall effect on growth of the Laccaria isolates, while the remaining streptomycete isolates reduced fungal growth significantly ( $\alpha = .05$ ).

Work in 1986 will continue to focus primarily on streptomycete levels and types associated with washed mycorrhizal roots. Duplicate samples per plot (i.e., six samples per site) will be analyzed for each sampling date, in order to provide more data points for statistical analysis of the 1986 data (both alone and in comparison with the 1985 data). The same streptomycete morphological scheme used in 1985 will be emphasized in 1986. Root tip enrichment studies will continue, on a limited basis, with multiple tips per flask and with use of the filter membrane growth technique to increase streptomycete recovery (Polsinelli

Table 28. Effects of representative streptomycetes isolated from Elf plantation red pine mycorrhizae on radial growth (mm) by three Laccaria spp. isolates.

Streptomycete <sup>a</sup> Isolate	<u>Laccaria</u> Isolate <sup>b</sup>		
	<u>L. bicolor</u> <sup>c</sup>	<u>L. bicolor</u> <sup>d</sup>	<u>L. laccata</u> <sup>e</sup>
	1 PF	813	5
AS-B	21.0 ± 1.7	10.5 ± 2.1	16.3 ± 1.5
GS-P	9.0 ± 7.0	8.0 ± 4.2	6.0 ± 2.6
GS-B	26.7 ± 0.6	18.7 ± 1.5	14.5 ± 2.1
GS-B	26.0 ± 2.6	19.0 ± 1.7	14.0 ± 1.0
GS-F	25.3 ± 0.6	19.7 ± 2.5	18.0 ± 0.0
GS-L	24.0 ± 0.7	14.5 ± 0.7	12.5 ± 0.7
GS-F	25.3 ± 1.5	18.7 ± 1.2	16.0 ± 0.0
GS-T	9.0 ± 3.0	4.0 ± 2.0	no growth
Control	23.3 ± 0.7	20.3 ± 1.0	21.1 ± 0.8

- <sup>a</sup> Streptomycete isolates are identified here by site of isolation (AS - antenna site, GS - antenna ground site) and type designation (according to Table 24).  
<sup>b</sup> Radial growth (mm) is reported as the mean ± S.D. of three replicates.  
<sup>c</sup> This isolate was collected from the La Croix red pine plantation, near Atlantic Mine, MI.  
<sup>d</sup> This isolate was obtained from Sylvan Spawn, Kittanning, PA.  
<sup>e</sup> This isolate was collected from a red pine plantation on the Danaher Plains, Schoolcraft Co., MI.

Table 29. Two-way ANOVA table for analysis of differences in radial growth by three Laccaria spp. isolates in the presence of eight streptomycetes isolated from type 3 mycorrhizal red pine roots between study sites and sampling dates.

Source of Variation	Degrees of Freedom	Mean Square	F	Signif. of F
Main Effects	10	291.839	74.906	.000
<u>Laccaria</u> Isolate	2	332.103	85.241	.000
Strep. Isolate	8	300.080	77.021	.000
Two-way Interactions	15	19.130	4.910	.000
<u>Laccaria</u> x Strep	15	19.130	4.910	.000
Explained	25	128.214	32.909	.000
Residual	62	3.896		
Total	87	39.620		

and Mazza 1984). Streptomyces recovered through the enrichment study will continue to be typed according to the same method employed with streptomyces isolated from the washed mycorrhizal fine roots to help assess if changes in specific streptomycete/mycorrhiza associations are occurring with time or between sampling sites. Streptomycete/mycorrhizal fungus pure culture interaction studies will not be conducted on a routine basis; some testing will be done to determine if the predominant streptomycete types found in 1985 and 1986 have any positive or negative effects on the mycorrhizal fungi actually detected from the red pine planted at the ELF sites.

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APPENDIX A.

Exponential Models Derived from 1983-84 Red Pine Mass Loss Data

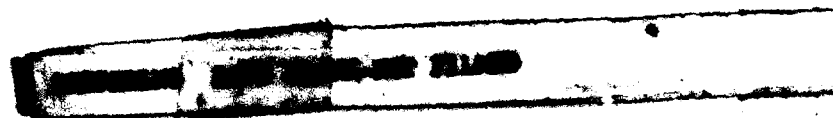


Table A-1. Characteristics of single exponential models<sup>a</sup> tested for fit with first year overall mass loss from fresh-fallen pine foliar litter at the overhead and ground sites.

	Fascicles <sup>b</sup>			Bulk Samples <sup>c</sup>		
	Antenna Site		Ground Site	Antenna Site		Ground Site
	Pole-stand	Plantation	Plantation	Pole-stand	Plantation	Plantation
$X = e^{-kt} ; k_i = 7.50 \times 10^{-4}$						
$k (x 10^{-4})$	7.53	7.06	7.05	7.42	7.01	7.06
$SD_k (x 10^{-5})^d$	1.0	1.2	1.1	1.7	2.1	2.4
$df^e$	262	280	275	53	53	53
$CI_k$ upper $(x 10^{-4})^f$	7.73	7.30	7.27	7.76	7.43	7.54
$CI_k$ lower $(x 10^{-4})$	7.33	6.82	6.83	7.08	6.59	6.58
$X = e^{-k(t-l)} ; k_i = 7.5 \times 10^{-4} , l_i = 100$						
$k (x 10^{-3})$	1.10	1.13	1.09	1.07	1.05	1.09
$SD_k (x 10^{-5})$	3.4	2.8	3.7	4.4	4.9	5.6
$l$	88	95	88	87	85	91
$SD_l$	5.5935	3.7271	5.2119	7.6570	7.7056	8.1426
$df$	261	279	274	52	52	52
$CI_k$ upper $(x 10^{-3})$	1.17	1.19	1.16	1.16	1.15	1.20
$CI_k$ lower $(x 10^{-3})$	1.03	1.07	1.02	0.98	0.95	0.98
$CI_l$ upper	99	102	98	102	100	107
$CI_l$ lower	77	88	78	72	70	75
$X = e^{-k(t-89)} ; k_i = 7.50 \times 10^{-4} , l_i = 100$						
$k (x 10^{-3})$	1.11	1.10	1.10	1.09	1.07	1.08
$SD_k (x 10^{-5})$	1.3	1.3	1.6	1.7	2.2	2.5
$df$	262	280	275	53	53	53
$CI_k$ upper $(x 10^{-3})$	1.14	1.13	1.13	1.12	1.11	1.13
$CI_k$ lower $(x 10^{-3})$	1.08	1.07	1.07	1.06	1.03	1.03

a/ Models were derived using BMDP4R, for derivative-free nonlinear regression. Mass loss is expressed as the proportion (X) of initial mass remaining at time of sampling (t); k is the decomposition rate constant ( $k_i$  is the estimate of k used to initiate the iterative process); l is the lag period in days. Samples were retrieved monthly from mid-May through early December.

b/ Fascicle samples consist of bagged (9 in x 6 in, 3 mm mesh, nylon envelopes), individually identified, perfectly-forced fascicles.

c/ Bulk samples consist of 10 g of bagged (12 in x 8 in, 3 mm mesh, nylon envelopes) pine fascicles.

d/ asymptotic standard deviation

e/ degrees of freedom

f/ upper and lower bounds of confidence interval ( $\alpha = 0.05$ )

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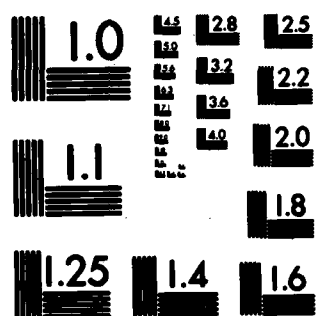
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Figures A-1 through A-6.

Figure A-1. Forms of single exponential model best fitting overall mass loss by bulk pine samples at the three study locations without a lag period.

Figure A-2. Forms of single exponential model best fitting overall mass loss by individual pine fascicles at the three study locations without a lag period.

Figure A-3. Forms of single exponential model best fitting overall mass loss by bulk pine samples at the three study locations with independently determined lag periods.

Figure A-4. Forms of single exponential model best fitting overall mass loss by individual pine fascicles at the three study locations with independently determined lag periods.

Figure A-5. Forms of single exponential model best fitting overall mass loss by bulk pine samples at the three study locations with lag period of 89 days.

Figure A-6. Forms of single exponential model best fitting overall mass loss by individual pine fascicles at the three study locations with lag period of 89 days.

Figure A-1.

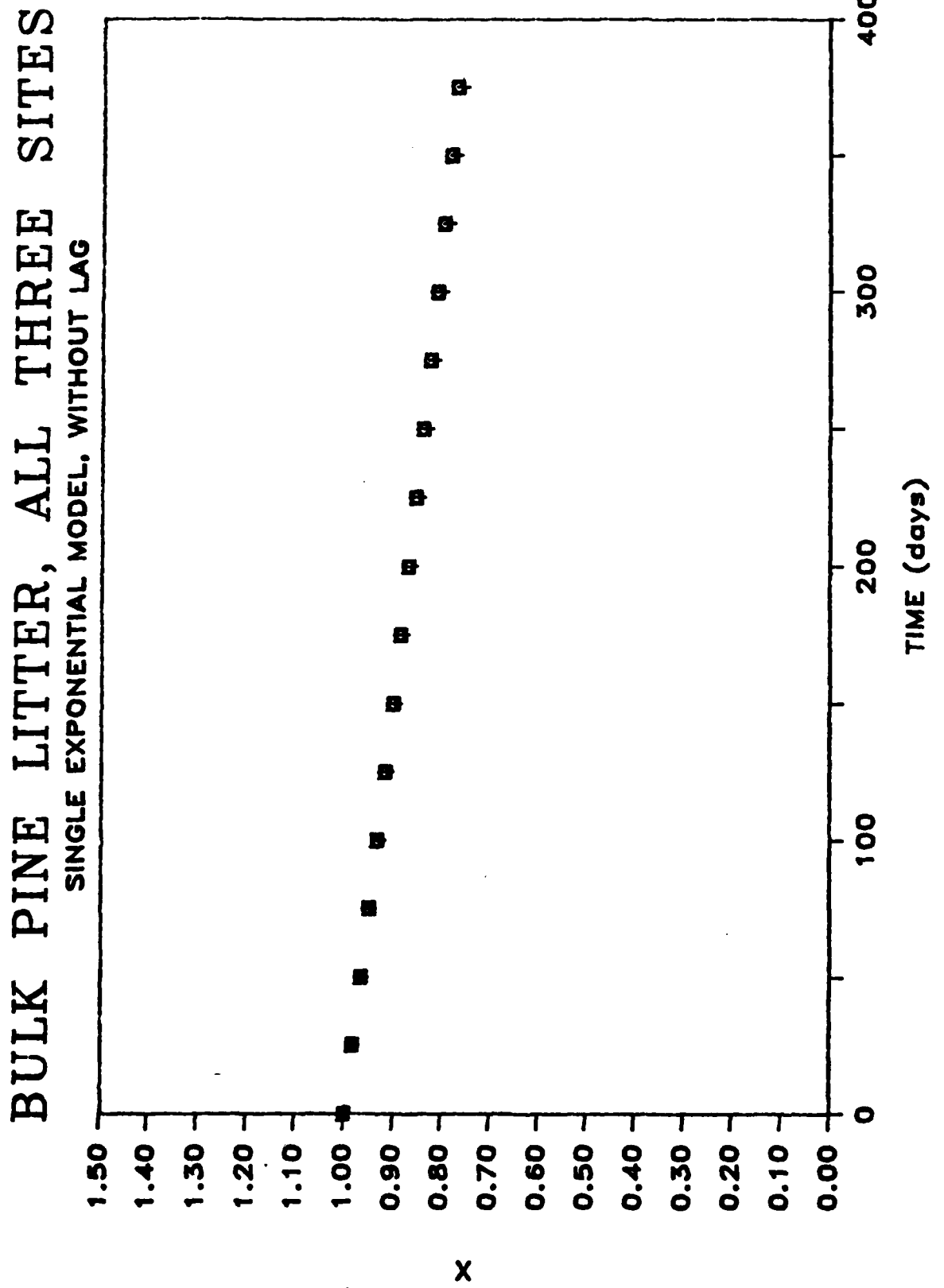




Figure A-2.

# PINE FASCICLES, ALL THREE SITES

SINGLE EXPONENTIAL MODEL, WITHOUT LAG

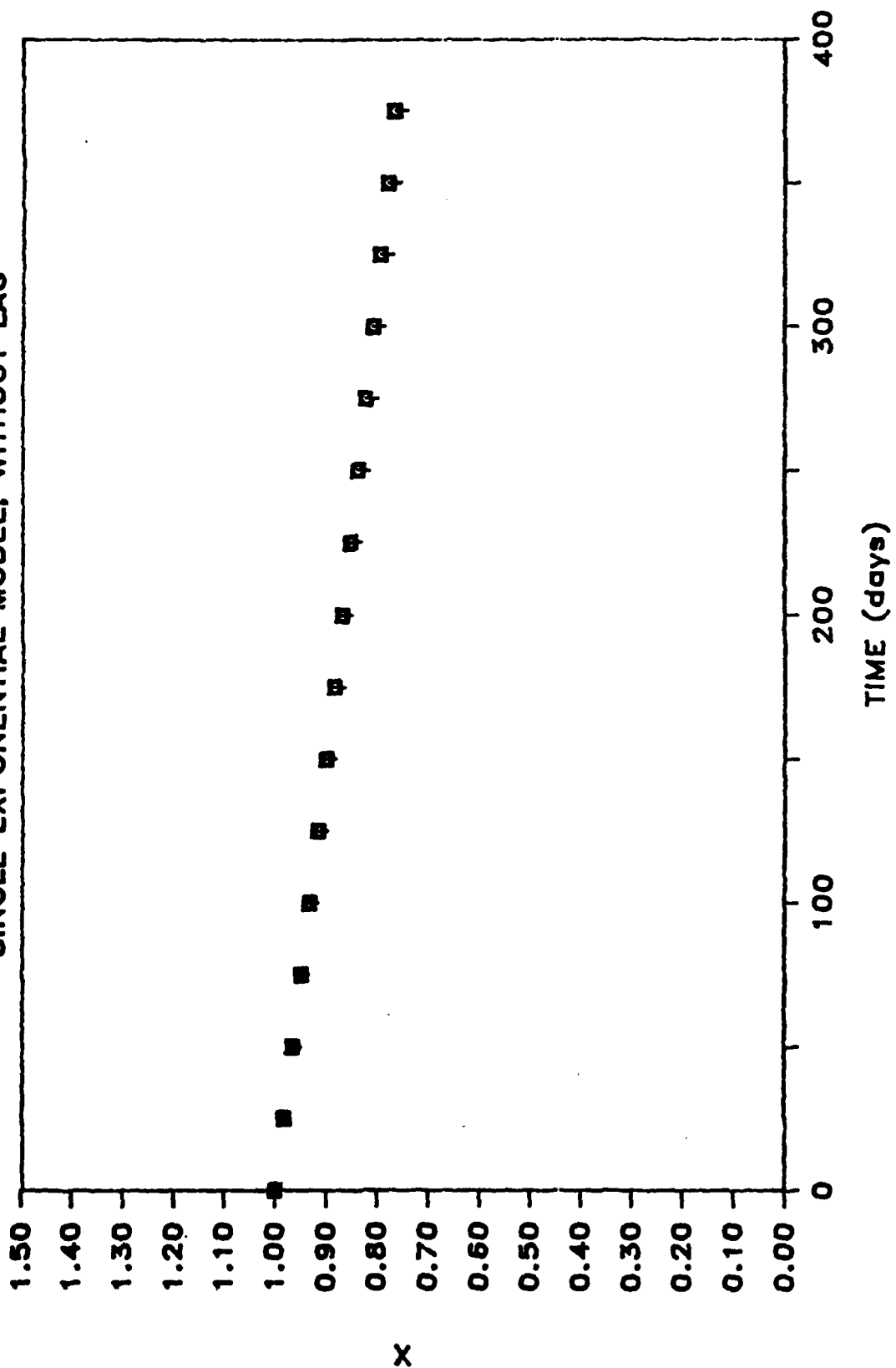


Figure A-3.

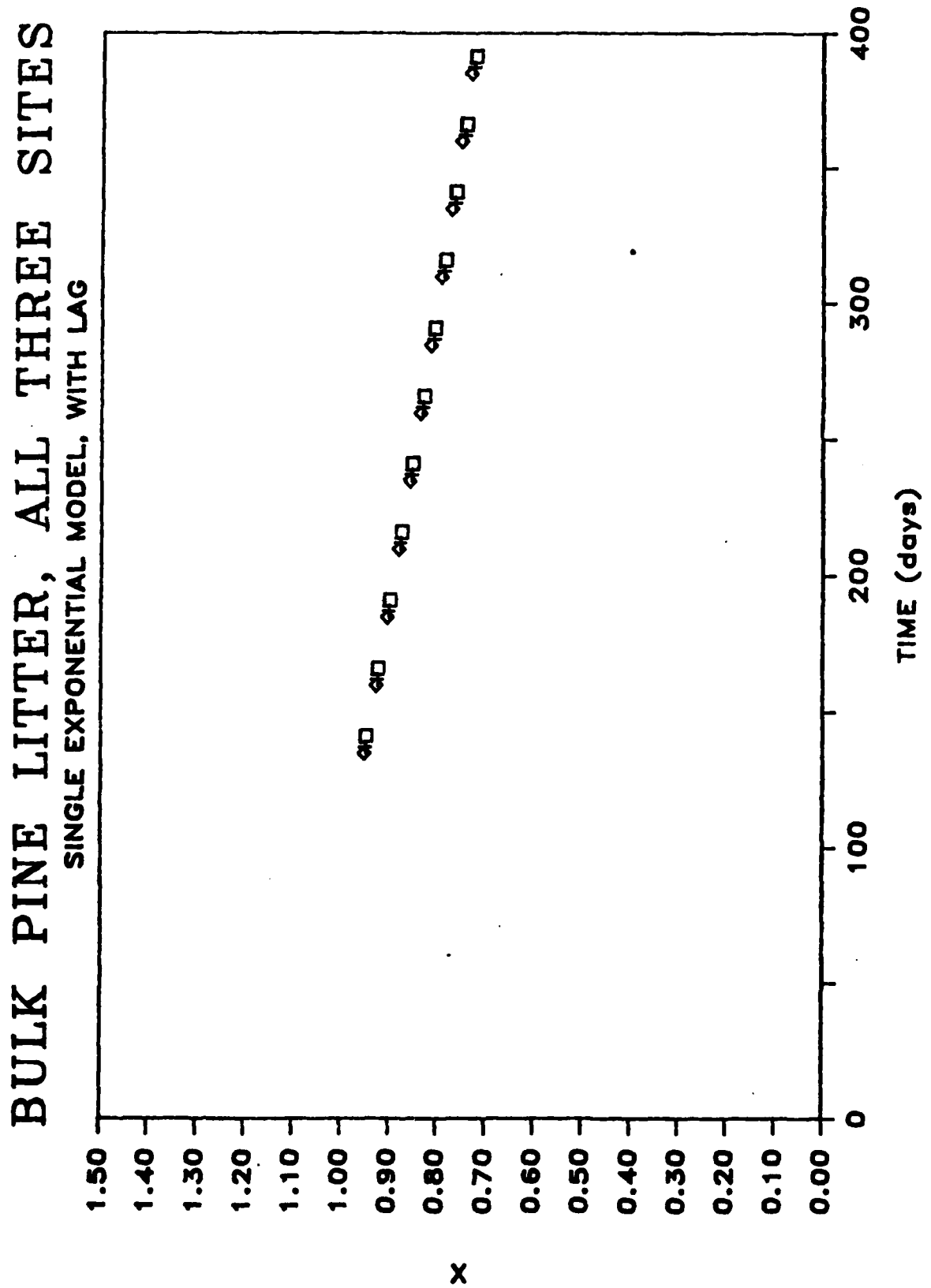


Figure A-4.

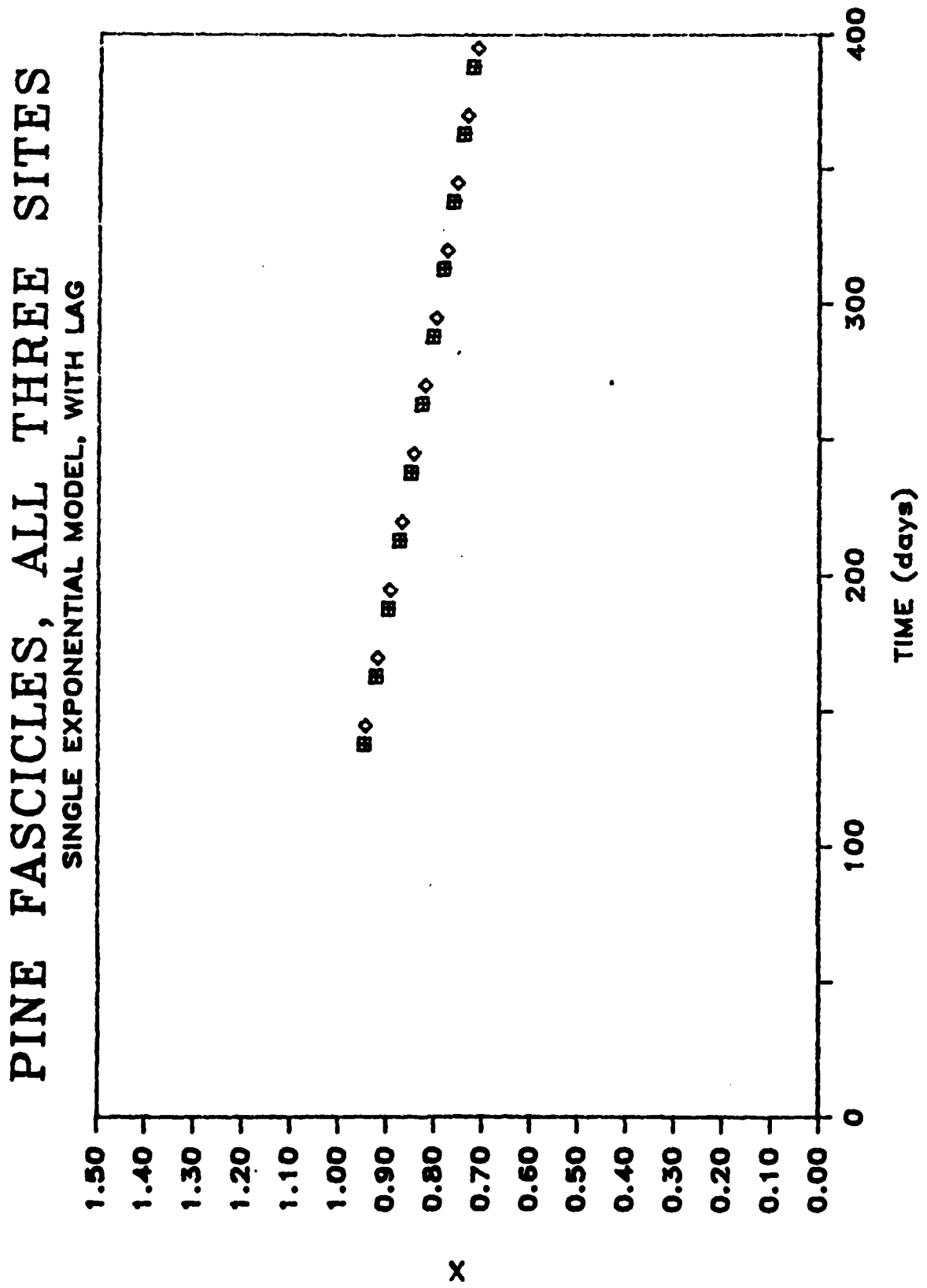


Figure A-5.

# BULK PINE LITTER, ALL THREE SITES SINGLE EXPONENTIAL MODEL, 89 DAYS LAG

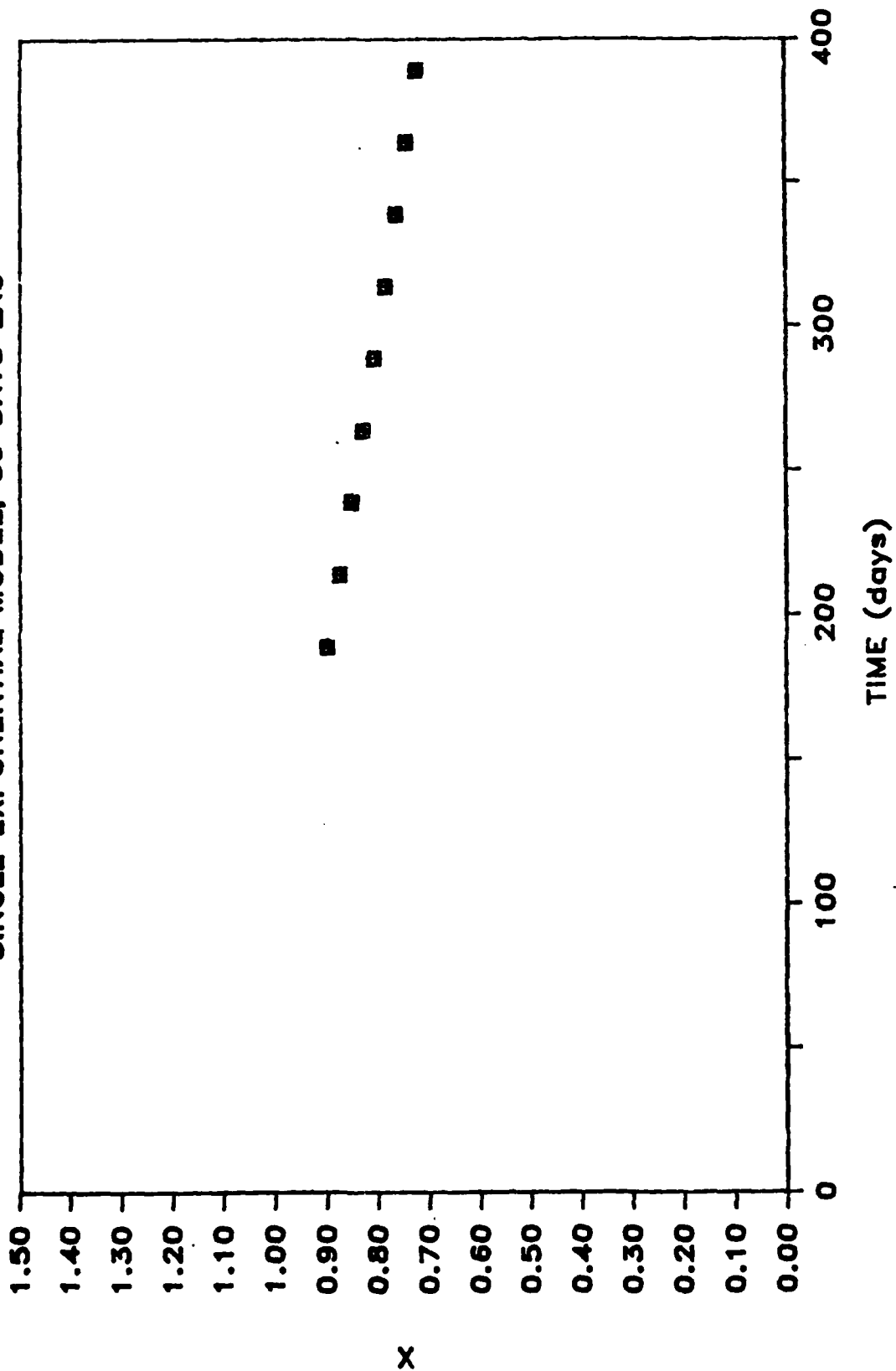
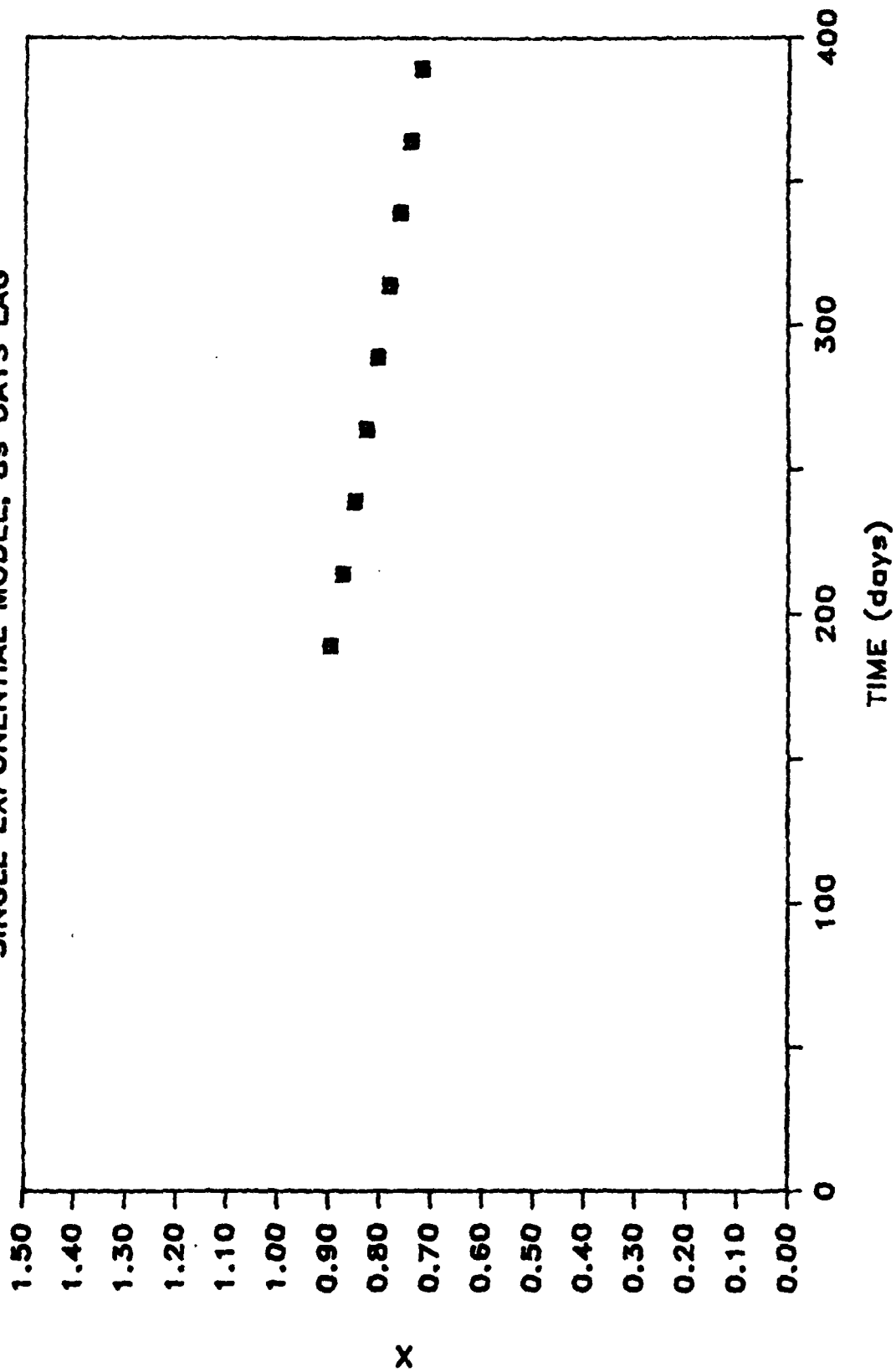


Figure A-6.

# PINE FASCICLES, ALL THREE SITES SINGLE EXPONENTIAL MODEL, 89 DAYS LAG




**Eugene M. Goodman**

**Biomedical Research Institute  
University of Wisconsin-Parkside  
Kenosha, Wisconsin 53141**


**Subcontract #E6549-84-C-009**

**"ELF Communications System Ecological Monitoring Program"**  
**The Effects of Exposing the Slime Mold Physarum polycephalum**  
**to Electromagnetic Fields**

**January, 1986**



**Eugene M. Goodman**  
**Principal Investigator**



**B. Greenebaum**  
**Co-Investigator**



**Gary Goetz**  
**Assistant Chancellor,**  
**Administrative Affairs**

## **GLOSSARY - ACRONYMS**

<b>Respiration:</b>	A measurement of the rate of oxygen utilization.
<b>Antenna ground:</b>	A conducting connection between the transmitting antenna and the earth.
<b>Axenic culture:</b>	Growth of a single organisms (slime mold) in the absence of contaminating organisms such as bacteria, fungi, etc.
<b>Plasmodium:</b>	A mass of protoplasm visible to the eye containing numerous nuclei; the entire structure is delimited by a plasma membrane. In the laboratory is it usually maintained on a solid substrate such as agar or filter paper.
<b>Micro-plasmodia:</b>	Plasmodia maintained in submerged shake flasks.
<b>Shake flask cultures:</b>	A method of maintaining plasmodia in a liquid nutrient medium. The flask is continuously shaken to provide oxygen to the culture.
<b>Cell cycle:</b>	The number of hours between successive divisions of a cell; in this experiment it is the number of hours required for division of the nucleus.
<b>W.T.F.</b>	Wisconsin Testing Facility.
<b>ELF</b>	Extremely low frequency fields.
<b>I.I.T.R.I.</b>	Illinois Institute of Technology Research Institute.

## TABLE OF CONTENTS

INTRODUCTION .....	1
Selection of Control and Experimental Sites .....	2
Protocols for Field Exposure and Maintenance of <u>Physarum</u> .....	3
1. Field Exposure System .....	3
2. Culture Maintenance .....	5
Laboratory Exposure of <u>Physarum</u> .....	6
Temperature Effects .....	7
Results and Discussion of Laboratory Data .....	7
EFFECTS OF FIELD EXPOSURE AT THE WISCONSIN TEST FACILITY .....	8
1. Mitosis .....	8
2. Respiration .....	9
3. ATP .....	10
SUMMARY OF DATA .....	12
DATA .....	15
APPENDIX I. Location of Sites and Field Intensity	
Measurements .....	69
APPENDIX II. Daily Record of Temperatures at Field Sites .....	77
REFERENCES .....	81



## ABSTRACT

We have previously shown that continuous laboratory exposure of the slime mold Physarum polycephalum to extremely low frequency weak electromagnetic fields (ELF-EMF) similar to those generated by the Navy's ELF communication antenna can depress the rate of respiration and lengthen the mitotic cell cycle (Goodman et al. 1976, 1979, Greenebaum et al. 1982). We now seek to determine whether exposing Physarum to the actual field environment around the Wisconsin Test Facilities (WTF) communications antenna will induce an altered physiological state.

To answer this question, a research program comprising both a laboratory and field component has been developed. Since all of our earlier experiments involved only continuous ELF-EMF exposure, it was necessary to first determine whether intermittent ELF-EMF exposure was capable of altering the cell's physiology. This was important because the field experiments conducted during both 1983 and 1984 would be performed with the antenna operating in an intermittent mode. Thus, if the tightly controlled laboratory experiments indicated that intermittent exposure had no effect, there would be little reason to suspect that exposure to the fields around the antenna (in an uncontrolled environment) would induce significant physiological changes.

Experiments were performed in the laboratory during 1983/84 which the mold was exposed to a continuous 76 Hz, sinusoidal field (CW) 1.0 G., 1.0 V/m for 16 hours per day, 5 days/week. This exposure regimen lengthened the mitotic cell cycle and increased the respiration rate (Dec. 1983 report, Goodman et al. 1984). The lengthened mitotic cycle agreed with the previously reported results; however, the enhanced respiration rate was the opposite of our findings with continuous EMF exposure. These results suggest that in addition to field intensity and waveform, the exposure period is also an important parameter in elucidating the bio-effects of weak fields.

Experiments conducted in the laboratory during 1985 at field intensities approximately the same as those encountered at the ground site showed no statistically significant changes in the ATP content, respiration rate or length of the mitotic cell cycle. Similar data was also obtained with plasmodia actually exposed in the vicinity of the WTF antenna.

## INTRODUCTION

Previous laboratory experiments have shown that exposing the slime mold Physarum polycephalum to extremely weak electromagnetic fields (EMF) of 45-75 Hz, 10  $\mu$ T - 0.2 mT, and 0.035-1.0 V/m can depress both the cell's ATP levels and respiration rate, and lengthen the mitotic cell cycle (Goodman, et al. 1976,79; Marron et al. in press). The program described in this report addresses the question of whether exposure of Physarum to fields generated in the environment by the ELF antenna itself, can induce similar physiological perturbations.

To answer this question, a research program comprising both a laboratory and field component was undertaken. During 1983/1984, Physarum was exposed in the laboratory to a 76 Hz sinusoidal field of 0.1 mT, 1.0 V/m for 16 hours/day, 5 days/week. This exposure regimen lengthened the mitotic cell cycle and increased the cell's respiration rate (Goodman et al. 1984). The lengthened mitotic cycle was consistent with our earlier findings; however, the increase in the respiration rate was the opposite of our finding for continuous 24 hr/day exposure. Based on these data, we concluded that the exposure regimen, in addition to field intensity and waveform were factors in the induction of an EMF bioeffect.

During 1984, laboratory cultures were also continuously exposed to a 76 Hz MSK modulated field of 0.1 mT, 1.0 V./m. A small but significant decrease in the length of the mitotic cell cycle of the EMF-exposed cultures was observed (C = 24.76 hrs vs E = 24.54 hrs); no significant differences were obtained in the respiration rate ( $QO_2 = \mu l O_2$  consumed/min/mg protein), C = 0.79 vs E = 0.79.

Exposure of Physarum at the W.T.F. during 1984 produced a statistically significant increase in the mitotic cell cycle in cells exposed at the ground site (G site; see Appendix A for the specific exposure and control site locations). In these

experiments, the time required to reach the third, post-fusion mitosis (M-III) was examined; the data show an 8% increase ( $C = 24.00$  hrs vs  $E = 26.06$  hrs) in cultures exposed at the G-site. A significant alteration in the cell cycle (M-III) was observed at the new A-II site ( $C = 25.18$  hrs vs  $E = 26.67$  hrs). Examination of the second post-fusion mitosis (M-II) showed a difference at the A-II site but not at the G site.

Although these data are in general agreement with our laboratory experiments on intermittent field effects (1984 report), a more careful examination reveals a fundamental inconsistency with our earlier experiments on mitosis. We previously observed that when a lengthened mitotic cycle of about 30 minutes was observed at M-II, the succeeding mitosis (M-III) was lengthened by about 60 minutes (Goodman et al. 1976); thus succeeding delays appear to be additive. The W.T.F. data is not consistent with these findings. Although the W.T.F. effects are statistically significant, they are based on a limited number of data. In contrast our earlier laboratory data is based on more than 7 years of accumulated data and >35,000 analyses. In looking to explain this inconsistency, we began to examine how the cultures were handled during their return from the W.T.F. to Parkside to ascertain if the procedures might be impacting on some of our data. During the 1985 season, we altered our culture handling procedures; the resultant data are discussed in the report.

#### **SELECTION OF CONTROL AND EXPERIMENTAL SITES**

Three sites (1 control, 2 experimental) were used in the field studies during 1985. The first exposure site is located parallel to the west ground (G-3, see map, Appendix 1), the second (A-2) is located about 3 miles from the ground site below the antenna (see Appendix 1 for specific locations).

Field measurements at all sites were made both by IITRI at the beginning of the season, and by us at various times during the summer; these data are summarized in Appendix 1. Based on our field exposure data the antenna did not appear to be operating

at peak power (300 Amps) during most of the periods when our measurements were being made.

One problem detected by ITRI during 1984 was the fact that the electric field intensities in the soil exceeded those in the culture chamber. This difference is the result of a mismatch of the conductivities in the growth chamber system and the earth. This has been addressed by both increasing the distance between the collector electrodes and constructing a new outer chamber assembly that allows us to match the conductivity of the chambers and the soil. Another change in the culture boxes was the substitution of stainless steel for the carbon electrodes used the previous year.

#### **PROTOCOLS FOR FIELD EXPOSURE AND MAINTENANCE OF PHYSARUM:**

**Field Exposure System:** Plasmodia were placed in the vicinity of the W.T.F. antenna on May 18, 1985 and were maintained in the field until October 12, 1985. Cultures were grown in autoclavable polyethylene chambers (7" x 4" x 2-1/4") with a tight fitting top; two stainless steel electrodes have been placed 6" apart and about 1/4" from the bottom of each chamber. Two or three growth chambers were placed inside the outer protective chamber (10" x 10" x 12"); a tight fitting lid provides a waterproof environment for the cultures. A 1/2" U-shaped vent pipe was attached to the lid of the outer chamber to facilitate gas exchange. The protective chambers with the growth chambers inside were placed in a hole approximately 2" x 20" x 20"; 8" square copper collecting plates were buried about one meter from the of the hole (in line with the predominant electric field). Electric fields are brought to the growth boxes by wire leads that run from the collecting plates to a plug on the outer wall of the protective chamber.

The following procedure was used to match the conductivity of the chambers with the ground fields:

- (1) The ground E-field was measured with a 1-meter probe attached to a Fluke 8060A multimeter.

- (2) The minimum required chamber voltage [  $V_{CH}$  (min) ] is determined by multiplying the measured E-field value by 0.2.

$$V_{CH} \text{ (min)} = E \times 0.2 \text{ (volts)}$$

- (3) The test chamber is then connected to the electrodes and the voltage across test cell ( $V_{CL}$ ) determined. A variable resistor is adjusted so that the voltage across the test cell is equal to  $V_{CL}$  as determined by the formula:

$$V_{CL} = E \times 0.155 \text{ (volts)}$$

- (4) The voltage across the 100 ohm series resistor ( $V_R$ ) is measured enabling determination of the cell current and current density.

To protect the exposure system from direct sunlight, foraging animals, etc., each hole was covered with a plywood board. One new problem encountered during the 1985 season was that animals frequently disturbed the "A" site; the net result was that the A-1 and A-2 chambers were often disconnected from the collector plates. This problem was resolved about mid-August. Each exposure site contained at least three protective chambers with their associated cultures. Two of the chambers were used for E-field exposure, and the third was used to examine the effects of current density.

During the early part of the season, temperature was continuously monitored at each site using 7-day, mechanical temperature recorders (Bacharach-Tempscribes) placed in each of the protective chambers. Because of reliability problems, the spring-wound recorders were replaced by battery-driven Dickson monitors in July. A temperature summary shows that the C-1 site tracked slightly warmer (1-2° F) during the latter part of the season (see Appendix 2). This finding is consistent with the temperature data

collected during the 1984 season.

**Culture Maintenance:** The field exposed cultures were maintained in an axenic state on a medium consisting of 50% growth medium (Daniel and Baldwin, 1964) 1% (w:v) sterile, rolled oats (Quaker), and 3% agar; 150 mls of sterile medium was placed in each growth container. All media preparation and sterilizations were performed at UW-Parkside; growth containers were placed in sterilized plastic bags and transported to the exposure site. Cultures at the W.T.F. were held for a week in a plexiglass chamber fitted with a bank of timer controlled, uv lights; examination of the boxes before subculturing the plasmodium ensured that the growth boxes had not become contaminated during transport from Parkside to the W.T.F.

To transfer the cultures in the field, the following protocols were followed: (1) The outer chambers were disconnected from the collector plates and brought to the mobile lab where the outside of the container was thoroughly washed to remove mud and dirt. (2) The growth chambers were removed, and the outer surfaces cleaned using a disposable wipe saturated with the disinfectant-Zorbicide™. (3) The growth chambers were placed in a Baker, laminar-flow hood and the plasmodia subcultured to fresh growth medium by excising a 2.5 cm square piece of culture at the advancing or growing front. Samples were simultaneously taken for experiments on mitosis and  $QO_2$  by placing plasmodia either onto a Petri dish (containing the same growth medium), or into a bottle containing 50% liquid growth media (diluted with water). These protocols generally proved effective and minimal contamination was encountered during the entire field season.

Plasmodia that had been exposed at the W.T.F. and placed in 50% liquid nutrient media, were returned to Parkside, and immediately placed on a shaker. This represents a change from 1984 procedures where cells were not placed on a shaker until the following morning. As a result of this change cells are now on a shaker within 9 hours of inoculation to liquid media instead of the previous 21-hour delay. Within 24 hours of

returning to Parkside, plasmodia were re-transferred to fresh medium and maintained as shake flask cultures in 125 ml Erhlenmeyer flasks until growth was adequate to perform experiments on mitosis, ATP and  $QO_2$  (usually within 48 hours). In general, the time between removal from the test site and performance of the appropriate tests ranged between 2 to 5 days, depending on the rapidity with which cultures readapted to liquid growth conditions. Plasmodia that had been placed on Petri dishes containing nutrient agar were used to measure oxygen consumption with an S-3A Oxygen Analyzer (Applied Electrochemistry) generally within 48 hours of returning to Parkside.

**Laboratory Exposure of Physarum:** Microplasmodia were maintained as submerged shake flask cultures in rectangular boxes; stainless steel electrodes comprise two sides of the flask (Goodman *et al.* 1975). Microplasmodia were exposed to continuous (24 hrs/day, 7 days/week) 76 Hz MSK modulation of 17.5  $\mu$ T, and 1.0 V/m during the 1985 laboratory portion of the program; the function generator was supplied by IITRI.

**Macroplasmodia** maintained on agar were subjected to continuous 76 Hz (mod) 17.5  $\mu$ T magnetic fields and either 10 mV/m (matched current densities) or 800 mV/m (matched E-fields) electric fields. Thus, EMF exposure in the laboratory was at approximately the same magnitude as the cultures would encounter at the W.T.F. ground site. These exposures should be contrasted to the 0.1 mT and 1.0 V/m used in the laboratory during 1984. The nature of most of our experimental protocols required that cultures maintained and exposed on agar be placed in suspension or submerged shake culture before initiating an experiment. To accomplish this, macroplasmodia were transferred from agar to a liquid medium (50% growth medium, 50% water) for 24 hours and then retransferred to regular growth medium. The respiration rate was usually measured 48 hours after introduction of the stationary macroplasmodium into liquid medium using a YSI oxygen monitor. This culture handling protocol was essentially the same as the procedures followed for the W.T.F.-exposed plasmodia.



**Effect of Continuous Laboratory Exposure on  $QO_2$ :** The  $QO_2$  of cells exposed to the matched current density regimen (76 Hz (mod) 17.5  $\mu$ T, 10 mV/m) showed no significant differences after 172 days of laboratory exposure ( $C = .68$  vs  $E = 0.71$ , Table 1). Plasmodia exposed to the matched E-fields (76 Hz (mod) 17.5  $\mu$ T, 800 mV/m) for — days also showed no significant differences in their  $QO_2$  ( $C = .68$  vs  $E = .66$ , Table 2).

**Temperature Effects:** The effect of varying the growing temperature on the respiration rate was also investigated by maintaining plasmodia on agar at 64° F; normally, Physarum is maintained in the laboratory at 78° F. To perform an experiment plasmodia were removed from agar and handled as described above. Although the cells were maintained at a lower temperature during growth, once in submerged shake culture they are maintained at the same temperature as the controls (78° F) for at least 48 h prior to performing a measurement. This handling procedure also mimics the way W.T.F. cultures are handled. The  $QO_2$  data show that maintaining cells at temperature lower than the controls does not significantly alter their rate of respiration ( $C = .66$  vs  $CT = .68$ , Table 3) after they are transferred to the higher temperature. Although the  $QO_2$  was not affected, the actual amount of growth observed at the lower temperature was always less than in the control box.

**Effects of Continuous Laboratory Exposure on ATP Levels:** The close correlation between the respiration rate and ATP levels suggests that analysis of the cell's ATP level might also prove to be a useful probe. To extract ATP from plasmodia that had been grown and exposed to EMF's on agar, it was necessary to first subculture the plasmodia into liquid suspension culture as described above. About 48 hours after introduction into suspension culture, a 3.0 ml aliquot was placed in boiling Tris-borate buffer (pH 9.0) for 10 minutes to extract the ATP. The extract was centrifuged for 10 minutes at 20,000 x g; the supernatant was then analyzed for ATP using a luciferin-luciferase assay and a Packard-Picolite luminometer system. The residual pellet was analyzed for protein and the data was normalized in terms of nM ATP/mg protein. In many, but not all

experiments, the same cultures were used for analysis of both ATP and respiration.

Examination of ATP levels in cells in which the current density was being studied (76 Hz (mod) 17.5  $\mu$ T, 10 mV/m) showed no difference between control and exposed plasmodia (C = 21.64 vs E = 21.38, Table 4); similar results were obtained in the matched E-field experiment (C = 20.87 vs E = 17.77, Table 5). The ATP levels in cells subjected to lower growth temperature (64° F) also showed no significant difference (C = 20.87 vs C = 22.12, Table 6).

The laboratory data collected during 1985 on cultures maintained on agar and exposed to field intensities analogous to those encountered at the W.T.F. suggest that the cell's mitotic cycle (data not included), respiration rate and ATP content were not altered. Further, maintaining cells at a temperature considerably below the temperature of the control culture (14° F) does not appear to exert a residual effect. That is, once the cells are placed into suspension culture and grown for 48 hours at control temperatures (78° F), no significant differences are detected. These experiments are being continued to both decrease the scatter in the data and to increase the number of data. The latter is especially important in the ATP and mitosis experiments where the N is small.

#### **FIELD EXPOSURE EXPERIMENTS AT THE W.T.F.**

The fields at the G and A sites were routinely measured to determine the actual field exposure of the plasmodia. Examination of our field measurements (Appendix 1) when compared with the ITRI measurements show that the antenna was not at full power (300 amps) during most of the periods when field measurements were being made.

**Effect of Field Exposure on Mitosis:** Plasmodia were placed in the vicinity of the W.T.F antenna on May 18th. Samples were routinely collected and returned to UW-Parkside to determine the effect of field exposure on mitosis. Each site contains cultures exposed to matched E-fields (conductivities of the growth chamber matched to

the earth) and to the current density induced by the W.T.F. antenna. To analyze for trends and to prevent the data from the initial exposure periods of May and June from exerting a bias, an analysis of the data was done monthly (results not shown) and at the end of the season.

Cultures exposed at the ground site showed no significant alteration in their cell cycle. A comparison of the time required to reach M-III in plasmodia subjected to matched E-fields was C = 23.52h vs E = 23.97h (Table 7); the time to M-III in the current density exposure regimen was C = 25.2h vs E = 25.25h (Table 8).

Exposure of plasmodia at the A site also showed no significant effects on the timing of the mitotic cell cycle. The time required to reach M-III in cells exposed at the matched E-field site was C = 24.11h vs E = 23.77h (Table 9); no differences were observed in plasmodia subjected to current density exposure at this site, C = 25.2h vs E = 25.16h (Table 10).

Although field exposure at both the G and A sites showed no differences (relative to non-exposed controls) in the time required to reach M-III, this experiment was hampered by the loss in late July of the technician who scored mitosis. As a result, the field exposure data was essentially limited to 87 days; previous experiments in the lab suggest that this represents the minimum exposure period required to induce an effect. To prevent an event of this type from interfering with the program in the future, the various techniques being employed in this program will be taught to all of the participating personnel.

**Effects of Field Exposure on Respiration (Oxygen-Probe):** The suspension cultures used for mitosis were subcultured and used for respiration measurements. In general, the first measurements were made within 48 hours after returning to the laboratory; whenever possible, the samples were subcultured and re-examined. The latter procedure thus allowed us to gather more data points from a given week's exposure. Examination of the  $QO_2$  ( $\mu l O_2$  consumed/mg protein/min) from cultures exposed to matched E-fields at

the ground site showed no statistically significant differences ( $C = .59$  vs  $E = .59$ , Table 11 ); similar results were obtained from current density exposure at this site ( $C = .63$  vs  $E = .63$ , Table 12).

Plasmodia exposed to matched E-fields at the A-site also failed to show any statistically significant differences in their  $QO_2$ 's ( $C = .59$  vs  $E = .59$ , Table 13); no significant effects were detected in cells exposed to the current density protocol ( $C = .62$  vs  $E = .63$ , Table 14).

In contrast to some of our 1984 results, significant differences were not observed in the  $QO_2$ 's of plasmodia exposed during 1985. This may be due to more judicious handling of the cultures on the return to the lab, or to more stringent control of the field exposure regimens instituted this year.

**Oxygen Consumption Using the S-3A Analyzer on Macroplasmodia:** In these experiments samples of macroplasmodia growing at the C, A and G-sites were subcultured to Petri plates (containing 15 ml of growth medium and agar) at the same time plasmodia were transferred. The plates were returned to the laboratory and analyzed with the S-3A monitor within 48 hours. Because we again encountered difficulties with this instrument half-way through the season, the experimental data have not been included, however, the data we did collect were in agreement with the oxygen probe experiments in showing no significant effects.

**ATP Levels in Field-Exposed Plasmodia:** Cultures used for mitosis and  $QO_2$  measurements were also used to assess the effect of weak fields on the cells' ATP content; the latter is expressed as nM ATP/mg protein. Cells exposed to matched E-fields at the ground site (147 days) showed no significant effect of their ATP levels ( $C = 21.1$  vs  $20.7$ , Table 15); current density exposure at the G site showed no effect ( $C = 22.3$  vs  $22.1$ , Table 16).

Exposure to the matched E-fields at the A-site showed no significant effect on the plasmodium's ATP level ( $C = 22.6$  vs  $25.4$ , Table 17). Matched current density exposure

at the A-site also showed no effect on the ATP level ( $C = 23.8$  vs  $E = 24.8$ , Table 18).

**Statistics:** The statistical routines have been discussed in depth in previous reports. Briefly, a parametric paired t-test and a non-parametric randomization are employed. The parametric test is used as a quick and approximate measure of statistical significance of a difference. The randomization is relied upon to assess the significance of an observed difference. A two-way analysis of variance (ANOVA) was not performed on the 1985 data since statistical significance was not shown in either of the tests we currently employ. Given the fact that significant differences were not found, the wisdom of running a more powerful test was not apparent.

Summary of electromagnetic field exposure conditions and qualitative results of experiments conducted during the 1985 field season.

Location	Site	Type of Matched Exposure (electric field [E] or current density [J])	APPROXIMATE 76 Hz ELECTROMAGNETIC FIELD PARAMETERS				SIGNIFICANT EXPOSURE EFFECT ON:			
			Calculated on basis of pre-trial data [P] or 1985 season [S]	Earth Electric Field (mV-m-1)	Electric Field (mV-m-1)	Current Density (mA-m-2)	Magnetic Field (uT)	Mitotic Interval	ATP Content	Respiratory Rate
WTF	G	E	P	±880 ±620	±870 ±630	±180 ±150	--	No	No	No
		J	P	±910 ±630	±10 ±4	±2 ±1	--	No	No	No
A	E	P	P	±210 ±190	±210 ±250	±44 ±40	--	No	No	No
		J	P	±200 ±200	±2 ±2	±0.4 ±0.4	--	No	No	No
C	E	P	P	±1 --	±2 --	±0.4 --	--	--	--	--
		J	P	±1 --	±0 --	±0 --	--	--	--	--
LABORATORY	E	-	-	--	800	--	17.5	No*	No	No
		J	-	--	10	--	17.5	No*	No	No

\*Data not presented. Page 8 (lines 8-10) statement: "The laboratory data collected during 1985... suggest that the cell's mitotic cycle, respiration rate and ATP content were not altered."

# DATA SUMMARY - LABORATORY EXPERIMENTS

Experiment	Exposure Condition	Control	Experimental	P (significance)
$\mu\text{l O}_2$ consumed/mg protein/min	$76\text{H}_2$ (mod) $17.5 \mu\text{T}$ , 10 mV/m	.68	.71	—
$\mu\text{l O}_2$ consumed/mg protein/min	$76\text{H}_2$ (mod) $17.5 \mu\text{T}$ , 800 mV/m	.68	.66	—
$\mu\text{l O}_2$ consumed/mg protein/min	decreased temperature	.66	.68	—
nMATP/mg protein	76 Hz (mod) $17.5 \mu\text{T}$ , 10 mV/M	22.64	21.64	—
nMATP/mg protein	$76\text{H}_2$ (mod) $17.5 \mu\text{T}$ , 800 mV/m	20.87	17.77	—
nMATP/mg protein	decreased temperature	20.87	22.12	—

# DATA SUMMARY - FIELD EXPERIMENTS

Experiment	Exposure Site	Control	Experimental	P (significance)
Mitosis (III)	G (matched E-fields)	23.52	23.97	—
Mitosis (III)	G (current density)	25.20	25.25	—
Mitosis (III)	A (matched E-fields)	24.11	23.77	—
Mitosis (III)	A (current density)	25.20	25.16	—
$\mu$ l O <sub>2</sub> consumed/mg protein/min	G (matched E-field)	.59	.59	—
$\mu$ l O <sub>2</sub> consumed/mg protein/min	G (current density)	.63	.63	—
$\mu$ l O <sub>2</sub> consumed/mg protein/min	A (matched E-field)	.59	.59	—
$\mu$ l O <sub>2</sub> consumed/mg protein/min	A (current density)	.62	.63	—
nMATP/mg protein	G (matched E-field)	21.1	20.7	—
nMATP/mg protein	G (current density)	22.3	22.1	—
nMATP/mg protein	A (matched E-field)	22.6	25.4	—
nMATP/mg protein	A (current density)	23.8	24.8	—



**TABLE 1**

**Summary of Effects of Continuous Laboratory Exposure to 76 Hz., (mod),  
17.5  $\mu$  T, 10 mV/m of Physarum polycephalum**

These tables compare the oxygen consumption in Control and EMF-exposed (matched current density) microplasmodia. The summaries show the overall average  $QO_2$  for Experimental and Control cultures, the average difference and the standard deviation of the difference. This is followed by the number of data (NTOT), the Degrees of Freedom, and the T-Statistic. A double star indicates the data are significant at  $p < .01$ , the level we require before accepting an EMF effect.

The second data set recomputes the T-statistic after removing one day's data at a time. The purpose of this routine is to insure that a single day difference does not bias the final statistical conclusion.

Table 1 (Continued)  
C vs E<sub>III-1</sub>

DAY/	EXP'T'L	CONTROL
6-3-85/	.973 .715 .898	.791 .824 .883
6-7-85/	.576 .746 .59	.647 .78 .78
6-11-85/	.875 .798 .61	.765 .667 .673
6-18-85/	.739 .678 .725	.67 .64 .579
7-10-85/	.682 .601 .564	.562 .543
8-1-85/	.783 .902 .908	.791 .775 .716
8-23-85/	.789 .885 .632	.75 .782 .761
10-8-85/	.954 .989 .894	.861 .924 .738
10-31-85/	.631 .565 .557	.577 .582 .524
11-1-85/	.904 .689 .729	.789 .678 .647
11-12-85/	.574 .472 .441	.59 .647 .659
11-21-85/	.575 .524 .487	.42 .372 .436
11-22-85/	.647 .604 .621	.72 .683 .684
*****		

Table 1 (Continued)

C vs E<sub>III-1</sub> (Continued)

```

*****
OVERALL AVERAGE          .71          .68
AVERAGE DIFFERENCE          .03
STANDARD DEV OF DIFF      .016
*****
NTOT=                      77
DEG OF FREEDOM=           51
T-STATISTIC=              1.68
*****
*p<.05          **p<.01

```

-----  
 RECOMPUTE T-STATISTIC REMOVING ONE DAY AT A TIME  
 -----

REMOVE DAY	T-STATISTIC	DEG OF FREEDOM
1. 6-3-85	1.6723	47
2. 6-7-85	2.2782*	47
3. 6-11-85	1.5307	47
4. 6-18-85	1.2943	47
5. 7-10-85	1.4245	48
6. 8-1-85	1.2179	47
7. 8-23-85	1.7752	47
8. 10-8-85	1.2371	47
9. 10-31-85	1.5838	47
10. 11-1-85	1.4589	47
11. 11-12-85	2.3816*	47
12. 11-21-85	1.1273	47
13. 11-22-85	2.0245*	47

\*\*\*\*\*

**TABLE 2**

**Summary of Effects of Continuous Laboratory Exposure to 76 Hz., (mod),  
17.5  $\mu$ T, 800 mV/m on the  $QO_2$  ( $\mu$ l  $O_2$  consumed mg protein/min)  
of Physarum polycephalum**

These tables compare the oxygen consumption in Control and EMF-exposed (matched electric field) microplasmodia. The summaries show the overall average  $QO_2$  for Experimental and Control cultures, the average difference and the standard deviation of the difference. This is followed by the number of data (NTOT), the Degrees of Freedom, and the T-Statistic. A double star indicates the data are significant at  $p < .01$ , the level we require before accepting an EMF effect.

The second data set recomputes the T-statistic after removing one day's data at a time. The purpose of this routine is to insure that a single day difference does not bias the final statistical conclusion.

Table 2 (Continued)  
C vs E<sub>III-2</sub>

DAY/	EXP'T'L	CONTROL
6-11-85+/	.686 .604 .649	.765 .667 .673
6-12-85/	.499 .478 .413	.679 .757 .704
6-18-85/	.668 .736 .678	.67 .64 .579
7-10-85/	.601 .603 .577	.562 .543
8-1-85/	.794 .793 .812	.791 .715 .716
8-5-85/	.768 .796 .738	.789 .713 .792
8-7-85/	.881 .754 .721	.775 .771
10-8-85/	.939 .678 .891	.861 .924 .738
10-31-85/	.536 .531 .496	.577 .5812 .524
11-1-85/	.794 .659 .688	.789 .678 .647
11-15-85/	.439 .41 .417	.458 .478 .457
*****		
OVERALL AVERAGE	.66	-.02
AVERAGE DIFFERENCE		.68
STANDARD DEV OF DIFF		.014
*****		
NTOT=	64	
DEG OF FREEDOM=	42	
T-STATISTIC=	1.33	
*****		
*P<.05	**P<.01	

C vs E<sub>III-2</sub> (Continued)

Table 2 (Continued)

RECOMPUTE T-STATISTIC REMOVING ONE DAY AT A TIME

REMOVE DAY	T-STATISTIC	DEG OF FREEDOM
*****	*****	*****
1. 6-11-85+	1.0031	38
2. 6-12-85	.3084	38
3. 6-18-85	1.7932	38
4. 7-10-85	1.6323	39
5. 8-1-85	1.7368	38
6. 8-5-85	1.3737	38
7. 8-7-85	1.5266	39
8. 10-8-85	1.7188	38
9. 10-31-85	1.08	38
10. 1-1-85	1.5134	38
11. 11-15-85	1.0537	38
*****	*****	*****

**TABLE 3**

**The Effect on the  $QO_2$  (  $\mu l O_2$  consumed/mg protein/min)  
of Physarum Maintained on Agar at 64° F**

These tables compare the oxygen consumption if plasmodia maintained on agar in the laboratory at 78° F (Control) with plasmodia maintained at 64° F. (Experimental). The summaries show the overall average  $QO_2$  for Experimental and Control cultures, the average difference and the standard deviation of the difference. This is followed by the number of data (NTOT), the Degrees of Freedom, and the T-Statistic. A double star indicates the data are significant at  $p < .01$ , the level we require before accepting an EMF effect.

The second data set recomputes the T-statistic after removing one day's data at a time. The purpose of this routine is to insure that a single day difference does not bias the final statistical conclusion.

Table 3 (Continued)  
C vs C<sub>T</sub>

DAY/	EXP'T'L	CONTROL
6-3-85/	.858 .881	.791 .824 .883
6-7-85/	.674	.647 .78 .78
6-11-85/	.6456 .695 .593	.765 .667 .673
6-17-85/	.653 .721 .689	.67 .64 .579
7-10-85/	.61 .598 .616	.5612 .543
7-16-85/	.73 .664 .71	.791 .775 .716
8-5-85/	.889 .77 .813	.789 .713 .792
8-7-85/	.822 .753 .779	.775 .771
8-23-85/	.756 .654 .641	.75 .782 .761
10-31-85/	.708 .653	.577 .582 .524
11-12-85/	.747 .627 .614	.59 .657 .659
11-15-85/	.533 .524 .532	.458 .478 .457
12-6-85+/	.512 .51 .469	.47 .426 .487
*****		



Table 3 (Continued)

C vs C<sub>T</sub> (Continued)

```

*****
OVERALL AVERAGE      .68                      .66
AVERAGE DIFFERENCE      .02
STANDARD DEV OF DIFF      .01
*****
NTOT=                72
DEG OF FREEDOM        46
T-STATISTIC=          1.58
*****
*p<.05                **p<.01

```

-----  
RECOMPUTE T-STATISTICS REMOVING ONE DAY AT A TIME  
-----

REMOVE DAY	T-STATISTIC	DEG OF FREEDOM
1. 6-3-85	1.3556	43
2. 6-7-85	2.3211*	44
3. 6-11-85	2.1313*	42
4. 6-17-85	1.1812	42
5. 7-10-85	1.176	43
6. 7-16-85	2.0711*	42
7. 8-5-85	1.2062	42
8. 8-7-85	1.5305	43
9. 8-23-85	2.2772*	42
10. 10-31-85	.708	43
11. 11-12-85	1.4857	42
12. 11-15-85	1.0833	42
13. 12-6-85+	1.323	42

\*\*\*\*\*

**TABLE 4**  
**ATP Levels (n M ATP/mg protein) in Physarum Subjected to**  
**76 Hz (mod) 17.5  $\mu$ T, 10 V/m (matched current density)**  
**in the Laboratory**

These tables compare the effect on the ATP content in Control and EMF-exposed plasmodia that had been maintained on agar and transferred to suspension culture for the experiment. The average difference and the standard deviation of the difference is followed by the number of data (NTOT), the Degrees of Freedom and the T-Statistic. A double star indicates the data are significant at  $p < .01$ , the level we require before accepting an EMF effect.

The second data set recomputes the T-statistic after removing one day's data at a time. The purpose of this routine is to insure that a single day difference does not bias the final statistical conclusion.

Table 4 (Continued)  
C vs E<sub>III</sub>

DAY/	EXP'T'L	CONTROL
5-3-85/	15.35 18.03	18.36 18.79
5-23-85/	17.8 22.68	19.44 19.31
6-25-85/	13.85 14.76	12.73 21.7
8-1-85/	25.56 26.84	29.43 28.1
8-6-85/	30.92 27.88	21.23 27.28
OVERALL AVERAGE	21.38	21.64
AVERAGE DIFFERENCE	-.26	
STANDARD DEV OF DIFF	1.27	
NTOT=	20	
DEG OF FREEDOM	10	
T-STATISTIC=	.2123	
*P<.05	**P<.01	

RECOMPUTE T-STATISTIC REMOVING ONE DAY AT A TIME

REMOVE DAY	T-STATISTIC	DEG OF FREEDOM
1. 5-3-85	.0861	8
2. 5-23-85	.3772	8
3. 6-25-85	.3478	8
4. 8-1-85	.1931	8
5. 8-6-85	1.2066	8

**TABLE 5**  
**ATP Levels (nM ATP/mg protein) in Physarum subjected to**  
**76 Hz (mod) 17.5  $\mu$  T, 800 V/m (matched E-fields)**  
**in the Laboratory**

These tables compare the effect on the ATP content in Control and EMF-exposed plasmodia that had been maintained on agar and transferred to suspension culture for the experiment. The average difference and the standard deviation of the difference is followed by the number of data (NTOT), the Degrees of Freedom and the T-Statistic. A double star indicates the data are significant at  $p < .01$ , the level we require before accepting an EMF effect.

The second data set recomputes the T-statistic after removing one day's data at a time. The purpose of this routine is to insure that a single day difference does not bias the final statistical conclusion.

# C vs E<sub>III2</sub>

Day/	EXP'T'L	CONTROL
5-3-85/	18.04 16.14	18.36 18.79
5-22-85/	13.17 8.83	17.48 21.87
6-25-85/	14.01 18.35	12.73 21.7
8-1-85/	26.32 27.79	29.43 28.1
8-6-85/	18.83 17.75	21.23 27.28
8-23-85/	18.08 15.92	20.92 12.49

```

*****
OVERALL AVERAGE      17.77      20.87
AVERAGE DIFFERENCE      -3.10
STANDARD DEV. OF DIFF.      1.34
*****
NTOT=      24
DEG OF FREEDOM=      12
T-STATISTIC=      2.31*
*****
*p<.05      **p<.01

```

## RECOMPUTE T-STATISTIC REMOVING ONE DAY AT A TIME

REMOVE DAY	T-STATISTIC	DEG OF FREEDOM
1. 5-3-85	2.1411	10
2. 5-22-85	1.3333	10
3. 6-25-85	2.7791*	10
4. 8-1-85	2.1135	10
5. 8-6-85	1.697	10
6. 8-23-85	2.7906*	10

**TABLE 6**

**ATP Levels (nM ATP/mg protein) in Physarum Subjected to  
Lowered Growth Temperature in the Laboratory**

These tables compare the effect on the ATP content in Control and EMF-exposed plasmodia that had been maintained on agar and transferred to suspension culture for the experiment. The average difference and the standard deviation of the difference is followed by the number of data (NTOT), the Degrees of Freedom and the T-Statistic. A double star indicates the data are significant at  $p < .01$ , the level we require before accepting an EMF effect.

The second data set recomputes the T-statistic after removing one day's data at a time. The purpose of this routine is to insure that a single day difference does not bias the final statistical conclusion.

Table 6 (Continued)  
C vs C<sub>t</sub>

Day/	EXP'T'L	CONTROL
5-22-85/	20.87 15.88	17.48 21.87
5-3-85/	15.4 17.1	18.36 18.79
5-23-85/	15.36 18.84	12.73 21.7
8-1-85/	23.67 21.56	29.43 28.1
8-6-86/	25.81 24.79	21.23 27.28
8-23-85/	40.26 25.95	20.92 12.49
*****		
OVERALL AVERAGE	22.12	20.87
AVERAGE DIFFERENCE	1.25	
STANDARD DEV OF DIFF	1.78	
*****		
NTOT=	24	
DEG OF FREEDOM=	12	
T-STATISTIC=	.70	
*****		
*P<.05	**P<.01	

-----  
RECOMPUTE T-STATISTIC REMOVING ONE DAY AT A TIME  
-----

REMOVE DAY	T-STATISTIC	DEG OF FREEDOM
*****		
1. 5-22-85	.869	10
2. 5-3-85	.9249	10
3. 5-23-85	.8008	10
4. 8-1-85	1.2874	10
5. 8-6-85	.6339	10
6. 8-23-85	1.3053	10
*****		

**TABLE 7**

**Summary of the Effects of W.T.F. (Ground Site) Exposure to Electromagnetic Fields  
(Matched E-Fields) on the Mitotic Cell Cycle of Physarum polycephalum**

These tables compare the onset of the third mitotic division (following addition of medium) in Control and EMF exposed (Experimental) plasmodia. The summaries show the overall average time of Experimental and Control cultures. The number of days of actual field exposure and the day the experiment was performed is also shown. The average difference and the standard deviation of the difference is followed by the number of data (NTOT), the Degrees of Freedom and the T-Statistic. A double star indicates the data are significant at  $p < .01$ , the level we require before accepting an EMF effect.

The second data set recomputes the T-statistic after removing one day's data at a time. The purpose of this routine is to insure that a single day difference does not bias the final statistical conclusion.



Table 7 (Continued)  
C vs G<sub>1&2</sub>

DAYS OF EXPOSURE	DAY EXPERIMENT PERFORMED	EXP'T'L	CONTROL
+10	+12	20.75	20.53
		22.42	21.43
		21.17	21.45
		22.42	21.12
		22.42	21.22
+24	+26	20.55	20.77
		19.62	21.32
		20.22	
		20.55	
		20.82	[21.04]
38	+44	25.28	25.23
		23.98	25.23
		25.2	23.88
		25.63	24.07
		26.13	26.47
+45	+51	25.77	26.98
		25.8	25.85
		25.05	26.78
		24.73	26.45
		25.78	26.7
+59	+66	28.02	28.5
		28.42	28.6
		17.5	28.28
			17.33
+66	+68	19.92	21.95
		20.2	21.33
		20.57	21.33
			21.83
+80	+82	22.7	22.62
		21.55	21.78
		21.0	21.83
		22.38	
		22.5	
+87	+89	24	25.08
		23.2	24.73
		23.85	25.3
		24.18	25
		24.73	

\*\*\*\*\*

Table 7 (Continued)

C vs G<sub>182</sub> (Continued)

```

*****
OVERALL AVERAGE                22.97      23.52
AVERAGE DIFFERENCE            - .55
STANDARD DEV OF DIFF           .46
*****
NTOT=                          68
DEG OF FREEDOM=                52
T-STATISTIC=                   1.176
*****
*P<.05                        **P<.01

```

-----  
 RECOMPUTE T-STATISTICS REMOVING ONE DAY AT A TIME  
 -----

REMOVE DAY	T-STATISTIC	DEG OF FREEDOM
1. 5-30-85	1.3314	44
2. 6-13-85	1.022	47
3. 7-1-85	1.2349	44
4. 7-8-85	.8515	44
5. 7-23-85	3.0286**	47
6. 7-25-85	.828	47
7. 8-8-85	1.1819	46
8. 8-15-85	.8919	45

\*\*\*\*\*

**TABLE 8**  
**Summary of the Effects of Exposure to Electromagnetic Fields**  
**(current density) at the W.T.F. (Ground Site) on the**  
**Mitotic Cycle of Physarum polycephalum**

These tables compare the onset of the third mitotic division (following addition of medium) in Control and EMF exposed (Experimental) plasmodia. The summaries show the overall average time of Experimental and Control cultures. The number of days of actual field exposure and the day the experiment was performed is also shown. The average difference and the standard deviation of the difference is followed by the number of data (NTOT), the Degrees of Freedom and the T-Statistic. A double star indicates the data are significant at  $p < .01$ , the level we require before accepting an EMF effect.

The second data set recomputes the T-statistic after removing one day's data at a time. The purpose of this routine is to insure that a single day difference does not bias the final statistical conclusion.

Table 8 (Continued)  
C<sub>3</sub> vs G<sub>3</sub>

DAYS OF EXPOSURE	DAY EXPERIMENT PERFORMED	EXP'T'L	CONTROL
+24	+30	25.12	23.93
		24.62	25.42
		25.47	23.08
		25.55	23.93
.39]		25.82	25.58
+38	+42	25.63	25.65
		23.88	22.7
		24.73	23.92
.25]		25.35	24.75
+45	+50	25.62	24.33
		22.83	23.58
		22.8	24.15
		22.82	24.28
.1]		24.17	24.17
+52	+58	26.35	26.6
		26.18	25.77
		26.68	25.98
		25.95	26.33
.27]		27.32	26.67
+59	+65	25.57	27.57
		25.62	27.15
		24.9	27.17
		25.93	26.12
		27.37	27
*****			
OVERALL AVERAGE		25.25	25.20
AVERAGE DIFFERENCE			.05
STANDARD DEV OF DIFF		.24	
*****			
NTOT=		47	
DEG OF FREEDOM=		37	
T-STATISTIC=		.18	
*****			
*P<.05		**P<.01	

Table 8 (Continued)

 $C_3$  vs  $G_3$  (Continued)-----  
RECOMPUTE T-STATISTIC REMOVING ONE DAY AT A TIME  
-----

REMOVE	T-STATISTIC	DIG OF FREEDOM
1. 6-17-85	.658	29
2. 6-30-85	.4366	31
3. 7-7-85	.6443	29
4. 7-15-85	9.2E-03	29
5. 7-22-85	1.2545	30

-----

**TABLE 9**  
**Summary of the Effects of Exposure to Electromagnetic**  
**Fields (Matched E-fields) at the W.T.F. (A Site) on the**  
**Mitotic Cell Cycle of Physarum polycephalum**

These tables compare the onset of the third mitotic division (following addition of medium) in Control and EMF exposed (Experimental) plasmodia. The summaries show the overall average time of Experimental and Control cultures. The number of days of actual field exposure and the day the experiment was performed is also shown. The average difference and the standard deviation of the difference is followed by the number of data (NTOT), the Degrees of Freedom and the T-Statistic. A double star indicates the data are significant at  $p < .01$ , the level we require before accepting an EMF effect.

The second data set recomputes the T-statistic after removing one day's data at a time. The purpose of this routine is to insure that a single day difference does not bias the final statistical conclusion.

Table 9 (Continued)  
C vs A<sub>182</sub>

DAYS OF EXPOSURE	DAY EXPERIMENT PERFORMED	EXP'T'L	CONTROL
+10	+12	22.42	20.53
		22.12	21.43
		21.97	21.45
		22.33	21.12
			21.15
+24	+26	26.53	25.68
		25.37	26.23
		25.97	
		26.07	
		26.4	25.96
+31	+33	24.08	22.67
		24.07	23.78
		22.13	23.7
		23.82	23.23
+38	+40	25.65	25.63
		22.7	23.35
		23.92	24.73
		24.75	25.35
	+44	21.92	25.23
		21.13	25.23
		22.15	23.88
		21.57	24.07
		21.9	26.47
45	+51	26.67	26.98
		25.63	25.85
		26.17	26.78
		25.5	25.45
		26.32	26.7
59	+66	27.85	28.5
		28.02	28.6
		28.42	28.28
		17.5	
66	68	20	21.95
		21.9	21.33
		21.95	21.33
			21.83

C vs A<sub>1&2</sub> (Continued)

Table 9 (Continued)

DAYS OF EXPOSURE	DAY EXPERIMENT PERFORMED	EXP'T'L	CONTROL
80	+82	22.72 22.38 21.78 23.13	22.62 21.78 21.83 22.5
87	+89	25.08 24.68 24.92 23.83	25.08 24.73 25.3 25
*****			
OVERALL AVERAGE		23.77	24.11
AVERAGE DIFFERENCE		- .34	
STANDARD DEV OF DIFF		.40	
*****			
NTOT=		82	
DEG OF FREEDOM=		62	
T-STATISTIC=		.86	
*****			

RECOMPUTE T-STATISTIC REMOVING ONE DAY AT A TIME

REMOVE DAY	T-STATISTIC	DEG OF FREEDOM
*****		
1. 5-30-85	1.1152	55
2. 6-13-85	.9089	57
3. 6-20-85	.9178	56
4. 6-27-85	.7511	56
5. 7-1-85	.049	54
6. 7-8-85	.72	54
7. 7-23-85	2.2848*	56
8. 7-25-85	.8002	57
9. 8-8-85	.991	57
10. 8-15-85	.7666	56
*****		



**TABLE 10**  
**Summary of the Effects of Exposure to Electromagnetic Fields**  
**(Current Density) at the W.T.F. (A Site)**  
**on the Mitotic Cell Cycle of Physarum polycephalum**

These tables compare the onset of the third mitotic division (following addition of medium) in Control and EMF exposed (Experimental) plasmodia. The summaries show the overall average time of Experimental and Control cultures. The number of days of actual field exposure and the day the experiment was performed is also shown. The average difference and the standard deviation of the difference is followed by the number of data (NTOT), the Degrees of Freedom and the T-Statistic. A double star indicates the data are significant at  $p < .01$ , the level we require before accepting an EMF effect.

The second data set recomputes the T-statistic after removing one day's data at a time. The purpose of this routine is to insure that a single day difference does not bias the final statistical conclusion.

Table 10 (Continued)  
C<sub>3</sub> vs A<sub>3</sub>

DAYS OF EXPOSURE	DAY EXPERIMENT PERFORMED	EXP'T'L	CONTROL
+24	+30	23.88 22.82 25.1 24.62	23.97 25.42 23.08 23.93
+38	+42	25.63 23.88 24.73 25.35	25.65 22.7 23.92 24.75
.25]			
+45	+50	23.75 24.68 24.35 24.82 25.18	24.33 23.58 24.15 24.28 24.17
.1]			
+52	+58	25.92 25.5 25.42 25.92 26.33	26.6 25.98 26.33 26.67
.27]			
+59	+65	26.87 26.57 26.48 25.23 26.85	27.57 27.15 27.17 26.12 [27]
*****			
OVERALL AVERAGE		25.16	25.20
AVERAGE DIFFERENCE			-.04
STANDARD DEV OF DIFF		.22	
*****			
NTOT=		46	
DEG FREEDOM=		36	
T-STATISTIC=		.22	
*****			
*P<.05		**P<.01	

Table 10 (Continued)

 $C_3$  vs  $A_3$  (Continued)-----  
REMOVING T-STATISTIC REMOVING ONE DAY AT A TIME  
-----

REMOVE DAY	T-STATISTIC	DEG OF FREEDOM
1. 6-17-85	.0545	29
2. 6-30-85	1.0224	30
3. 7-7-85	.6418	28
4. 7-15-85	.1963	28
5. 7-22-85	.3589	29

-----

**TABLE 11**

**Summary of the Effects of Exposure to Electromagnetic Fields  
(Matched E-fields) on the W.T.F. (Ground Site)  
on the  $QO_2$  ( $\mu l O_2$  consumed mg protein/min)  
of Physarum polycephalum**

These tables compare the oxygen consumption in Control and EMF-exposed (matched electric field) microplasmodia. The summaries show the overall average  $QO_2$  for Experimental and Control cultures, the average difference and the standard deviation of the difference. This is followed by the number of data (NTOT), the Degrees of Freedom, and the T-Statistic. A double star indicates the data are significant at  $p < .01$ , the level we require before accepting an EMF effect.

The second data set recomputes the T-statistic after removing one day's data at a time. The purpose of this routine is to insure that a single day difference does not bias the final statistical conclusion.

Table 11 (Continued)

C<sub>182</sub> vs G<sub>182</sub>

DAYS OF EXPOSURE	DAY EXPERIMENT PERFORMED	EXP'T'L	CONTROL
+10	+12	.584	.423
		.497	.413
		.549	.344
	+19	.424	.458
		.507	.657
		.56	
+24	+26	.31	.428
		.335	.424
			.394
	+27	.535	.616
		.543	.675
		.555	.699
+31	+33	.597	.306
			.286
			.301
	+34	.615	.598
		.628	.627
		.642	.59
+38	+44	.575	.615
		.526	.599
		.607	.614
	+45	.599	.664
		.608	.631
		.552	.606
+45	+52	.64	.67
		.633	.665
		.6	.64
+52	+58	.606	.756
		.524	.641
		.63	.635
	59	.7	.739
		.664	.696
		.704	.576
	61	.854	.58
		.816	.258
		.811	

Table 11 (Continued)

C<sub>182</sub> vs G<sub>182</sub> (Continued)

DAYS OF EXPOSURE	DAY EXPERIMENT PERFORMED	EXP'T'L	CONTROL
+59	+66	.544	.627
		.541	.599
		.599	.596
	77	.68	.779
		.691	.748
+80	+89	.77	.726
		.64	.727
		.651	.687
	+95	.666	.71
		.594	.631
		.52	.553
+95	+102	.579	.569
		.548	.516
+103	+114	.736	.682
		.65	.703
		.598	.671
	+118	.633	.599
		.6	.612
		.6	.513
+119	+122	.564	.593
		.514	.571
		.549	
+135	+137	.637	.469
		.61	.5
		.628	
+147	+156	.665	.77
		.575	.734
		.518	
	158	.659	.716
		.681	.866
	160	.478	.521
		.444	.455
		.452	.491

\*\*\*\*\*

Table 11 (Continued)

## C1&amp;2 vs G1&amp;2 (Continued)

```

*****
OVERALL AVERAGE                .594                .594
AVERAGE DIFFERENCE            -
STANDARD DIV OF DIFF          9.1e-03
*****
NTOT=                          132
DEG OF FREEDOM=                84
T-STATISTIC=                   .0632
*****
*P<.05                        **P<.01

```

## RECOMPUTE T-STATISTIC REMOVING ONE DAY AT A TIME

REMOVE DAY	T-STATISTIC	DEG OF FREEDOM
1. 5-30-85	.6322	80
2. 6-6-85	.3678	81
3. 6-13-85	.4927	81
4. 6-14-85	.6112	80
5. 6-20-85	1.3307	82
6. 6-21-85	.0437	80
7. 7-1-85	.2474	80
8. 7-2-85	.2811	80
9. 7-9-85	.2188	80
10. 7-15-85	.4937	80
11. 7-16-85	.0246	80
12. 7-18-85	2.0865*	81
13. 7-23-85	.2745	80
14. 8-3-85	.428	82
15. 8-15-85	.1878	80
16. 8-21-85	.2492	80
17. 8-28-85	.1025	80
18. 9-9-85	.1764	80
19. 9-13-85	.1044	80
20. 9-17-85	.2473	81
21. 10-2-85	.5854	81
22. 10-21-85	.8518	81
23. 10-23-85	.6443	82
24. 10-25-85	.2057	80

\*\*\*\*\*

**TABLE 12**

**Summary of the Effects of Exposure to Electromagnetic Fields  
(Current Density) at the W.T.F. (Ground Site)  
on the  $QO_2$  ( $\mu l O_2$  consumed mg protein/min)  
of Physarum polycephalum**

These tables compare the oxygen consumption in Control and EMF-exposed (matched electric field) microplasmodia. The summaries show the overall average  $QO_2$  for Experimental and Control cultures, the average difference and the standard deviation of the difference. This is followed by the number of data (NTOT), the Degrees of Freedom, and the T-Statistic. A double star indicates the data are significant at  $p < .01$ , the level we require before accepting an EMF effect.

The second data set recomputes the T-statistic after removing one day's data at a time. The purpose of this routine is to insure that a single day difference does not bias the final statistical conclusion.



Table 12 (Continued)

 $C_3$  vs  $G_3$ 

DAYS OF EXPOSURE	DAY EXPERIMENT PERFORMED	EXP'T'L	CONTROL
+24	+26	.423	.422
		.427	.431
		.398	.419
	+27	.601	.619
		.599	.678
		.589	.743
+31	+34	.65	.661
		.624	.755
		.677	.832
+38	+44	.66	.617
		.646	.632
		.645	.613
	+45	.626	.651
		.699	.665
		.68	.687
+45	+51	.632	.418
		.629	.598
		.647	.527
	+52	.641	.678
		.685	.673
			.692
+52	+59	.601	.582
		.629	.567
		.565	.449
+59	+61	.502	.536
		.534	.553
		.52	.577
	+66	.604	.593
		.604	.614
		.623	.609
+66	+68	.722	.743
		.822	.762
			.72
+73	+77	.74	.643
		.862	.778
			.656
+80	+82	.859	.679
		.83	.693

Table 12 (Continued)

C<sub>3</sub> vs G<sub>3</sub> (Continued)

DAYS OF EXPOSURE	DAY EXPERIMENT PERFORMED	EXP'T'L	CONTROL
+87	+95	.595 .517 .497	.632 .501 .471
+95	102	.7 .613	.681 .706 .671
+103	+109	.622 .544 .508	.651 .639 .672
	+110	.704 .754 .587	.64 .658 .76
+110	+114	.798 .784	.764 .702 .647
	+118	.549 .501 .475	.553 .56 .471
+119	+122	.593 .59 .56	.738 .688 .7
+135	+137	.51 .468	.496
+147	+156	.674 .514 .515	.704 .659 .689
	+159	.697 .577 .501	.68 .673
	+160	.604 .681 .64	.684 .648

\*\*\*\*\*  
 OVERALL AVERAGE .628 .634  
 AVERAGE DIFFERENCE (C-E) -.006  
 STANDARD DEV OF DIFF .008  
 \*\*\*\*\*

NTOT= 134  
 DEG OF FREEDOM= 86  
 T-STATISTIC= .712  
 \*\*\*\*\*

\*P&lt;.05

\*\*P&lt;.01

Table 12 (Continued)

C<sub>3</sub> vs G<sub>3</sub> (Continued)-----  
RECOMPUTE T-STATISTIC REMOVING ONE DAY AT A TIME  
-----

REMOVE DAY	T-STATISTIC	DEG OF FREEDOM
1. 6-13-85	.6718	82
2. 6-14-85	.3166	82
3. 6-21-85	.2472	82
4. 7-1-85	.8508	82
5. 7-2-85	.718	82
6. 7-8-85	1.3398	82
7. 7-9-85	.6313	83
8. 7-16-85	1.0524	82
9. 7-18-85	.5362	82
10. 7-23-85	.7336	82
11. 7-25-85	.8742	83
12. 8-3-85	1.2968	83
13. 8-8-85	1.4942	84
14. 8-21-85	.7521	82
15. 8-28-85	.5805	83
16. 9-4-85	.2565	82
17. 9-5-85	.7278	82
18. 9-9-85	1.1518	83
19. 9-13-85	.6266	82
20. 9-17-85	.102	82
21. 10-2-85	.7003	83
22. 10-21-85	.1623	82
23. 10-24-85	.3238	83
24. 10-25-85	.6044	83

\*\*\*\*\*

**TABLE 13**  
**Summary of the Effects of Exposure to Electromagnetic Fields**  
**(Matched E-fields) at the W.T.F. (A Site)**  
**on the  $QO_2$  ( $\mu l O_2$  consumed mg protein/min)**  
**of Physarum polycephalum**

These tables compare the oxygen consumption in Control and EMF-exposed (matched electric field) microplasmodia. The summaries show the overall average  $QO_2$  for Experimental and Control cultures, the average difference and the standard deviation of the difference. This is followed by the number of data (NTOT), the Degrees of Freedom, and the T-Statistic. A double star indicates the data are significant at  $p < .01$ , the level we require before accepting an EMF effect.

The second data set recomputes the T-statistic after removing one day's data at a time. The purpose of this routine is to insure that a single day difference does not bias the final statistical conclusion.

Table 13 (Continued)

C<sub>1&2</sub> vs A<sub>1&2</sub>

DAYS OF EXPOSURE	DAY EXPERIMENT PERFORMED	EXP'T'L	CONTROL
+10	+12	.657	.423
		.542	.413
		.548	.344
	+19	.423	.458
		.46	.657
+24	+26	.527	.428
		.572	.424
		.555	.394
	+27	.623	.616
		.653	.675
		.749	.699
+31	+33	.265	.306
		.27	.286
		.283	.301
+38	+45	.646	.606
		.646	
+45	+52	.633	.67
		.634	.665
		.65	.64
+52	+58	.637	.756
		.633	.641
		.549	.635
	+59	.576	.696
		.555	.576
+80	+83	.662	.76
		.648	.68
		.694	
87	+89	.962	.726
		.944	.727
			.687
	+95	.497	.71
		.482	.631
		.416	.553

Table 13 (Continued)

C<sub>182</sub> vs A<sub>182</sub> (Continued)

DAYS OF EXPOSURE	DAY EXPERIMENT PERFORMED	EXP'T'L	CONTROL
+95	+102	.615 .624 .577	.628 .569 .516
+110	+122	.529 .459 .501	.593 .571
+135	+137	.707 .728 .685	.469 .5
+147	+156	.635 .509 .518	.77 .734
*****			
OVERALL AVERAGE		.590	.586
AVERAGE DIFFERENCE		.004	
STANDARD DEV OF DIFF		.01	
*****			
NTOT=		86	
DEG OF FREEDOM=		54	
T-STATISTIC=		.45	
*****			
*P<.05		**P<.01	

RECOMPUTE T-STATISTIC REMOVING ONE DAY AT A TIME

REMOVE DAY	T-STATISTIC	DEG OF FREEDOM
1. 5-30-85	.7673	50
2. 6-6-85	1.3248	52
3. 6-13-85	.4007	50
4. 6-14-85	.3944	50
5. 6-20-85	.6011	50
6. 7-2-85? .664	.1841	51
7. 7-9-85	.5667	50
8. 7-15-85	.9452	50
9. 7-16-85	.9414	52
10. 8-9-85	.7955	51
11. 8-15-85	1.0628	51
12. 8-21-85	1.5903	50
13. 8-28-85	.2403	50
14. 9-17-85	1.0043	51
15. 10-2-85	.9528	51
16. 10-21-85	1.7862	51
*****		

**TABLE 14**  
**Summary of the Effects of Exposure to Electromagnetic Fields**  
**(Current Density) at the W.T.F. (A Site)**  
**on the  $QO_2$  ( $\mu l O_2$  consumed mg protein/min)**  
**of Phyarrum polycephalum**

These tables compare the oxygen consumption in Control and EMF-exposed (matched electric field) microplasmodia. The summaries show the overall average  $QO_2$  for Experimental and Control cultures, the average difference and the standard deviation of the difference. This is followed by the number of data (NTOT), the Degrees of Freedom, and the T-Statistic. A double star indicates the data are significant at  $p < .01$ , the level we require before accepting an EMF effect.

The second data set recomputes the T-statistic after removing one day's data at a time. The purpose of this routine is to insure that a single day difference does not bias the final statistical conclusion.

Table 14 (Continued)

C<sub>3</sub> vs A<sub>3</sub>

DAYS OF EXPOSURE	DAY EXPERIMENT PERFORMED	EXP'T'L	CONTROL
+10	+12	.272 .211 .313	.193 .184 .197
+24	+26	.606 .626 .75	.422 .431 .419
+31	+34	.751 .752 .755	.661 .755 .832
+38	+44	.78 .653 .747	.617 .632 .613
	45	.597 .632 .617	.651 .665 .687
+45	+51	.638 .54 .524	.418 .598 .527
	52	.635 .627 .63	.678 .673 .692
+52	+58	.544 .529 .57	.732 .692 .749
	59	.532 .59 .64	.582 .567 .449
+59	+66	.637 .59 .649	.593 .614 .609
+66	+68	.808 .714 .623	.743 .762 .72
+80	+82	.799	.679 .693



Table 14 (Continued)

C<sub>3</sub> vs A<sub>3</sub> (Continued)

DAYS OF EXPOSURE	DAY EXPERIMENT PERFORMED	EXP'T'L	CONTROL
+95	+102	.714 .633 .664	.681 .716 .671
+103	+109	.653 .557 .516	.651 .639 .672
	110	.584 .654	.76 .64 .658
+110	+114	.717 .649 .582	.764 .702 .647
	+118	.659 .57 .497	.553 .56 .471
+119	+122	.632	.688 .7
+135	+137	.617 .671	.591 .496
+147	+156	.59 .594 .534	.704 .659 .689
	158	.696 .608 .588	.779 .617 .674
	160	.629 .656 .678	.68 .673

\*\*\*\*\*  
 OVERALL AVERAGE .27 .623  
 AVERAGE DIFFERENCE .004  
 STANDARD DIV OF DIFF .009  
 \*\*\*\*\*

NTOT= 124  
 DEG OF FREEDOM= 80  
 T-STATISTIC= .431  
 \*\*\*\*\*

\*p&lt;.05

\*\*p&lt;.01

Table 14 (Continued)

 $C_3$  vs  $A_3$  (Continued)-----  
RECOMPUTE T-STATISTIC REMOVING ONE DAY AT A TIME  
-----

REMOVE DAY	T-STATISTIC	DEG OF FREEDOM
1. 5-30-85	.0657	76
2. 6-13-85	.7589	76
3. 6-21-85	.4282	76
4. 7-1-85	.0948	76
5. 7-2-85	.6892	76
6. 7-8-85	.1789	76
7. 7-9-85	.6777	76
8. 7-15-85	1.3076	76
9. 7-16-85	.1668	76
10. 7-23-85	.3326	76
11. 7-25-85	.5865	76
12. 8-8-85	.1314	79
13. 8-28-85	.5286	76
14. 9-4-85	.838	76
15. 9-5-85	.7891	77
16. 9-9-85	.7286	76
17. 9-13-85	.2053	76
18. 9-17-85	.4622	77
19. 10-2-84	.0681	78
20. 10-21-85	.9855	76
21. 10-22-85	.759	76
22. 10-24-85	.546	77

**TABLE 15**

**Summary of Effects of Exposure to Electromagnetic Fields  
(Matched E-fields) at the W.T.F. (Ground Site)  
on ATP (nM ATP/mg protein) Levels in Physarum polycephalum**

These tables compare the effect on the ATP content in Control and EMF-exposed plasmodia. The average difference and the standard deviation of the difference is followed by the number of data (NTOT), the Degrees of Freedom and the T-Statistic. A double star indicates the data are significant at  $p < .01$ , the level we require before accepting an EMF effect.

The second data set recomputes the T-statistic after removing one day's data at a time. The purpose of this routine is to insure that a single day difference does not bias the final statistical conclusion.

Table 15 (Continued)

C<sub>1&2</sub> vs G<sub>1&2</sub>

DAYS OF EXPOSURE	DAY EXPERIMENT PERFORMED	EXP'T'L	CONTROL
+10	+19	7.99 6.02	9.24 21.92
+24	+27	31.72 15	22.74 35.99
+31	+33	17.76 16.33	10.87 14.34
+52	+55	15.06 15.29	22.73 23.63
+59	+61	17.6 18.38	10.42 11.87
	+66	14.9 19.38	10.7 10.64
+87	+89	25.58 22.88	27.23 22.72
	+90	36.15 33.4	26.72 34.05
	+94	13.39 12.46	7.58 13.94
+95	+101	23.25 16.22	18.2 22.96
+103	+109	27.39 27.61	25.48 29.51
+135	+139	14.38 13.93	13.84 16.81
+147	+159	39.48 37.9	37.89 43.12
		15.9 22.85	19.02 25.17

\*\*\*\*\*

Table 15 (Continued)

C<sub>1&2</sub> vs G<sub>1&2</sub> (Continued)

```

*****
OVERALL AVERAGE                20.65          21.05
AVERAGE DIFFERENCE              -.4
STANDARD DEV OF DIFF            1.13
*****
NTOT=                          56
DEG OF FREEDOM=                 28
T-STATISTIC=                    .35
*****
*P<.05                          **P<.01

```

-----  
RECOMPUTE T-STATISTIC REMOVING ONE DAY AT A TIME  
-----

REMOVE DAY	T-STATISTIC	DEG OF FREEDOM
1. 6-6-85	.2081	26
2. 6-14-85	.0377	26
3. 6-21-85	.6369	26
4. 7-12-85	.1543	26
5. 7-18-85	.7855	26
6. 7-23-85	.7685	26
7. 8-15-85	.309	26
8. 8-16-85	.6495	26
9. 8-20-85	.499	26
10. 8-27-85	.3097	26
11. 9-4-85	.355	26
12. 10-4-85	.2791	26
13. 10-24-85	.2407	26
14. 10-25-85	.1881	26

\*\*\*\*\*

**TABLE 16**

**Summary of Effects of Exposure to Electromagnetic Fields  
(Current Density) at the W.T.F. (Ground Site) on ATP  
(nM ATP/mg protein) Levels in Physarum polycephalum**

These tables compare the effect on the ATP content in Control and EMF-exposed plasmodia. The average difference and the standard deviation of the difference is followed by the number of data (NTOT), the Degrees of Freedom and the T-Statistic. A double star indicates the data are significant at  $p < .01$ , the level we require before accepting an EMF effect.

The second data set recomputes the T-statistic after removing one day's data at a time. The purpose of this routine is to insure that a single day difference does not bias the final statistical conclusion.

Table 16 (Continued)

C<sub>3</sub> vs 6<sub>3</sub>

DAYS OF EXPOSURE	DAY EXPERIMENT PERFORMED	EXP'T'L	CONTROL
+10	+19	8.95 10.56	15.67 16.32
+24	+27	26.03 22.46	33.08 30.56
+31	+33	29.6 21.05	16.92 20.31
+52	+55	15.22 15.48	19.65 18.76
+59	+61	16.96	15.3 14.83
+66	+68	25.57 32.51	24.57 29.02
+80	+82	47.6 43.76	36.81 34.51
+87	+89	25.9 26.03	28.72 33.05
	+94	7.31 12.92	8.05 10.33
+95	+101	17.58 22.76	18.75 22.12
+103	+109	25.78 23.96	25.48 29.51
+135	+139	13.14 14.9	13.84 16.81
+147	+160	22.35 29.21	20.8 25.2
*****			
OVERALL AVERAGE		22.10	22.27
AVERAGE DIFFERENCE			-.17
STANDARD DEV OF DIFF			.78
*****			
NTOT=		51	
DEG FREEDOM=		25	
T-STATISTIC=		.22	
*****			
*P<.05		**P<.01	

Table 16 (Continued)

 $C_3$  vs  $G_3$  (Continued)-----  
RECOMPUTE T-STATISTIC REMOVING ONE DAY AT A TIME  
-----

REMOVE DAY	T-STATISTIC	DEG OF FREEDOM
1. 6-6-85	.3983	23
2. 6-14-85	.5417	23
3. 6-21-85	.9932	23
4. 7-12-85	.1621	23
5. 7-18-85	.4173	24
6. 7-25-85	.483	23
7. 8-8-85	1.2363	23
8. 8-15-85	.2735	23
9. 8-20-85	.3243	23
10. 8-27-85	.2017	23
11. 9-4-85	.0419	23
12. 10-4-85	.0905	23
13. 10-25-85	.5397	23

\*\*\*\*\*



**TABLE 17**  
**Summary of Effects of Exposure to Electromagnetic Fields**  
**(Matched E-fields) at the W.T.F. A Site on ATP**  
**(nM ATP/mg protein) Levels in Physarum polycephalum**

These tables compare the effect on the ATP content in Control and EMF-exposed plasmodia. The average difference and the standard deviation of the difference is followed by the number of data (NTOT), the Degrees of Freedom and the T-Statistic. A double star indicates the data are significant at  $p < .01$ , the level we require before accepting an EMF effect.

The second data set recomputes the T-statistic after removing one day's data at a time. The purpose of this routine is to insure that a single day difference does not bias the final statistical conclusion.

Table 17 (Continued)

C<sub>1&2</sub> vs A<sub>1&2</sub>

DAYS OF EXPOSURE	DAY EXPERIMENT PERFORMED	EXP'T'L	CONTROL
+10	+19	18.91 7.48	9.24 21.92
+24	+27	30.67 21.72	22.74 35.99
+31	+33	21.5 14.31	10.87 14.34
+73	+76	30.29 29.46	28.9 19.86
+80	+82	46.6 46.43	42.79 44.99
	+83	26.51 29.47	25.67 22.55
+87	+89	36.79 36	27.23 22.72
	+94	11.58 16.79	7.58 13.94
+95	101	19.14 13.35	18.2 22.96
+103	109	42.32 33.06	25.48 29.51
+135	139	12.68 12.77	13.84 16.81
*****			
OVERALL AVERAGE		25.36	22.64
AVERAGE DIFFERENCE			2.72
STANDARD DEV OF DIFF			1.42
*****			
NTOT=		44	
DEG OF FREEDOM=		22	
T-STATISTIC=		1.91	
*****			
*P<.05		**p<.01	

Table 17 (Continued)

C<sub>1&2</sub> vs A<sub>1&2</sub> (Continued)-----  
RECOMPUTE T-STATISTIC REMOVING ONE DAY AT A TIME  
-----

REMOVE DAY	T-STATISTIC	DEG OF FREEDOM
*****	*****	*****
1. 6-6-85	2.471*	20
2. 6-14-85	2.4672*	20
3. 6-21-85	1.6291	20
4. 8-2-85	1.633	20
5. 8-8-85	1.7507	20
6. 8-9-85	1.6819	20
7. 8-15-85	1.1951	20
8. 8-20-85	1.7572	20
9. 8-27-85	2.259*	20
10. 9-4-85	1.3326	20
11. 10-4-85	2.091*	20
*****	*****	*****

**TABLE 18**  
**Summary of Effects of Exposure to Electromagnetic Fields**  
**(Current Density) at the W.T.F. A Site on ATP**  
**(nM ATP/mg protein) Levels in Physarum polycephalum**

These tables compare the effect on the ATP content in Control and EMF-exposed plasmodia. The average difference and the standard deviation of the difference is followed by the number of data (NTOT), the Degrees of Freedom and the T-Statistic. A double star indicates the data are significant at  $p < .01$ , the level we require before accepting an EMF effect.

The second data set recomputes the T-statistic after removing one day's data at a time. The purpose of this routine is to insure that a single day difference does not bias the final statistical conclusion.

Table 18 (Continued)  
C<sub>3</sub> vs A<sub>3</sub>

DAYS OF EXPOSURE	DAY EXPERIMENT PERFORMED	EXP'T'L	CONTROL
+10	+13	11.43 14.2	15.54 13.04
	+19	12.55 13.87	15.67 16.32
+24	+27	20.87 28.48	33.08 30.56
+31	+33	12.5	16.92 20.31
+38	+45	56.25 77.06	40.06 38.21
+52	+55	20.02 18.08	19.65 18.96
+59	+61	14.62 13.36	15.3 14.83
+66	+68	34.22 32.28	24.57 29.02
+80	+82	37.41 37.73	36.81 34.51
+87	+89	29.46 26.1	28.72 33.05
	+94	18.97 20.15	18.75 22.12
+103	+109	23.38 20.45	25.48 29.51
+135	+139	8.48 7.5	13.84 16.81
+147	+160	33.34 37.75	20.8 25.2

\*\*\*\*\*

Table 18 (Continued)

C<sub>3</sub> vs A<sub>3</sub> (Continued)

```

*****
OVERALL AVERAGE                24.75          23.84
AVERAGE DIFFERENCE              .91
STANDARD DEV OF DIFF            .96
*****
NTOT=                          55
DEG OF FREEDOM=                 27
T-STATISTIC=                    .95
*****
*P<.05                          **P<.01

```

-----  
RECOMPUTE T-STATISTIC REMOVING ONE DAY AT A TIME  
-----

REMOVE DAY	T-STATISTIC	DEG OF FREEDOM
1. 5-31-85	1.0648	25
2. 6-6-85	1.1532	25
3. 6-14-85	1.5509	25
4. 6-21-85	1.4547	26
5. 7-2-85	1.8427	25
6. 7-12-85	.9661	25
7. 7-18-85	1.0255	25
8. 7-25-85	.4719	25
9. 8-8-85	.8052	25
10. 8-15-85	1.202	25
11. 8-20-85	1.0188	25
12. 9-4-85	1.3849	25
13. 10-4-85	1.5009	25
14. 10-25-85	.0107	25

\*\*\*\*\*

## **APPENDIX I**

**Location and electromagnetic field intensity measurements at the sites used to determine the effects of exposure to the W.T.F. antenna.**



View of the west antenna ground right of way, looking south to west ground pole #N15 (stockade).



View of study plot with the buried culture chamber in place.

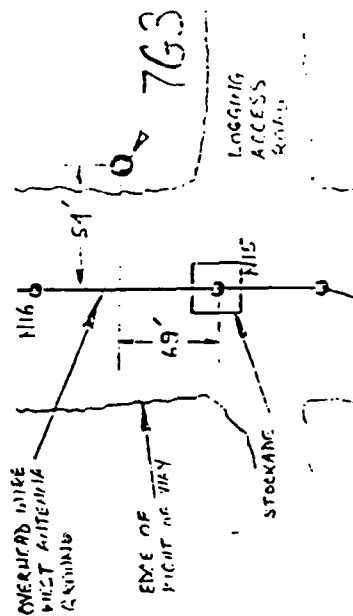
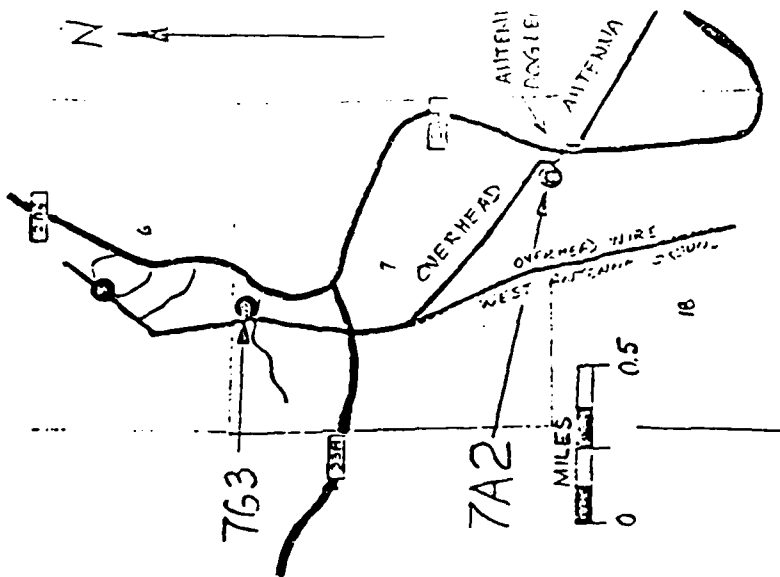


Figure 1. Site 7G3.



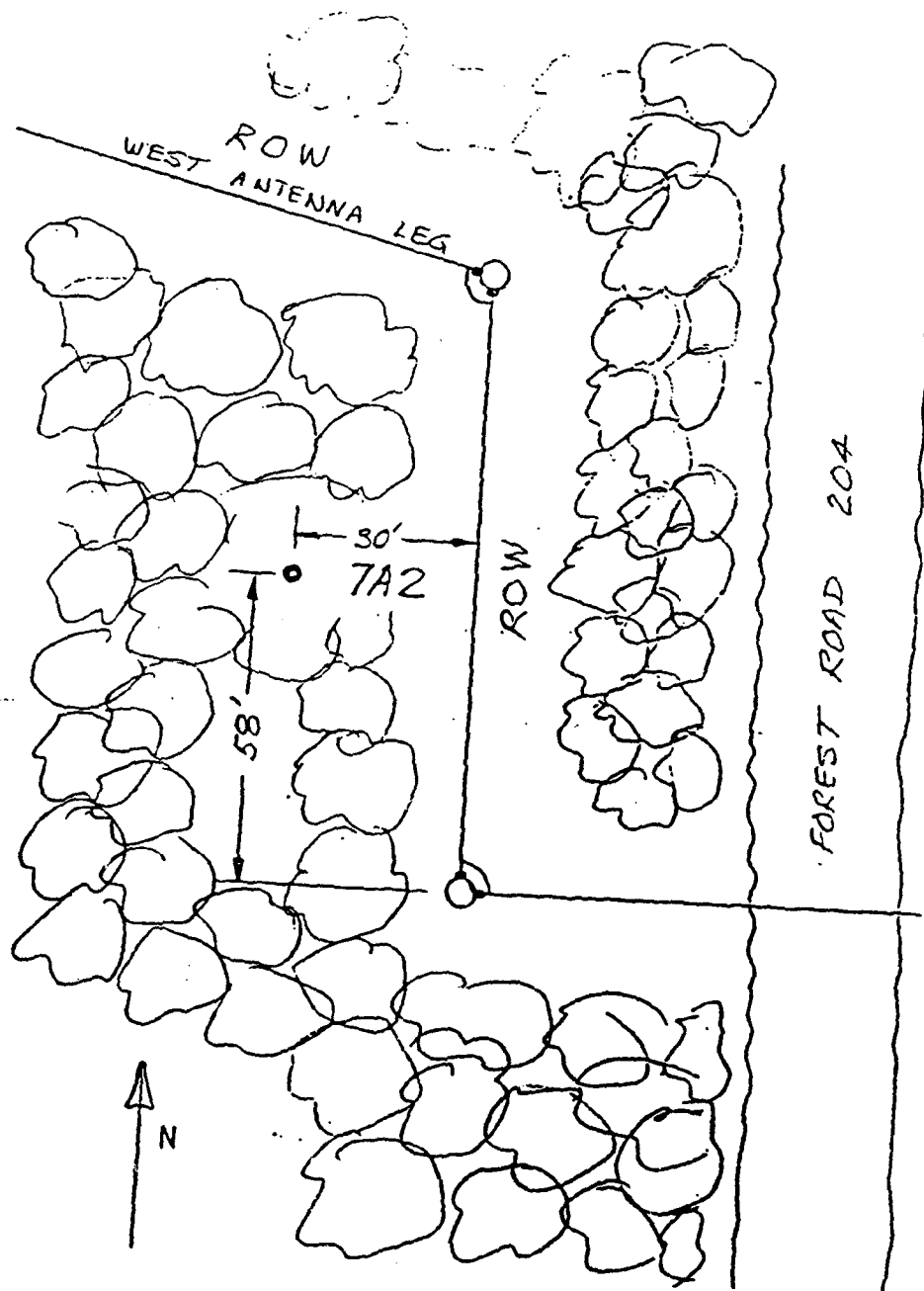


Figure 2. West antenna dogleg at FR 204.

# Slime Mold Study

## EM Measurements for Matched Current Density Chambers

Site/ Chamber	Frequency (Hz)	Earth Electric Field(1,2) E(mV/m)	Electrode Open-Circuit Voltage(2) V <sub>oc</sub> (mV)	Culture Cell Voltage(2,3) V <sub>CL</sub> (mV)	Current-Sense Resistor Voltage(2,3,4) V <sub>R</sub> (500K)(mV)	Calculated Culture Cell Current Density(5) J <sub>CL</sub> (mA/m <sup>2</sup> )	E-Field(6) E <sub>CL</sub> (mV/m)
7G3/North	76 (MSK)	900-920	920-980	1.52	950-970	2.11-2.16	9.84
	60	-	0.095	0.000128	0.095	0.00021	0.0008
7A2/South	76 (MSK)	194-200	190-193	0.28	190-191	0.42	1.81
	60	-	0.0145	0.00024	0.0155	0.000034	0.000152
7C1/North	76 (MSK)	1.0-1.05	2.06-2.13	0.0032-0.0033	2.06-2.10	0.0046-0.0047	0.021
	60	-	0.055	0.0001-0.0002	0.054	0.00012	0.00065-

- 1) Measured prior to exposure chamber burial.
- 2) Test site measurements do not include contribution of N/S antenna.
- 3) Test site measurements made with 1000 ohm resistor in place of test cell.
- 4) Test site data extrapolated for 800 ohm test cell.
- 5) Calculated from V<sub>R</sub> (see text).
- 6) Calculated from V<sub>CL</sub> (see text).

# Slime Mold Study

## EM Measurements for Matched E-Field Exposure Chambers

Site/ Chamber	Frequency (Hz)	Frequency Earth Field(1,2) E(mV/m)	Electrode Open-Circuit Voltage(2) V <sub>oc</sub> (mV)	Culture Cell Voltage(2,3) V <sub>CL</sub> (mV)	Current-Sense Resistor Voltage(2,3,4) V <sub>R</sub> (100)(mV)	Calculated Culture Cell Current Density(5) J <sub>CL</sub> (mA/m <sup>2</sup> )	E-Field(6) E <sub>CL</sub> (mV/m)
7G3/Center	76 (MSK)	776	1680-1860	120	13.8-14.1	153-158	774
	60	-	0.225	0.0135	0.00162	0.018	0.087
7G3/South	76 (MSK)	979	2140-2200	150	18.6-19.2	208-211	968
	60		0.235	0.017	0.00193	0.022	0.110
7A2/Center	76 (MSK)	212-216	487-495	33	4.02-4.13	44.6-45.9	213
	60	-	0.031	0.002	0.00024	0.0026	0.013
7A2/North	76 (MSK)	206-210	466-470	32	3.81-3.89	42.4-43.3	206
	60	-	0.031-0.032	0.00225	0.0003	0.0033	0.015
7C1/Center	76 (MSK)	0.88-0.92	4.1-4.25	0.275-0.28	0.037-0.038	0.41-0.42	1.80
	60	-	0.12	0.0079	0.0098	0.011	0.051
7C1/South	76 (MSK)	1.0	4.8-5.0	0.31-0.32	0.042	0.47	2.0
	60	-	0.14	0.0083	0.00115	0.013	0.054

- 1) Measured prior to exposure chamber burial.
- 2) Test site measurements do not include contribution of N/S antenna.
- 3) Test site measurements made with 1000 ohm resistor in place of test cell.
- 4) Test site data extrapolated for 800 ohm test cell.
- 5) Calculated from V<sub>R</sub> (see text).
- 6) Calculated from V<sub>CL</sub> (see text).

# 1985 MEASUREMENTS FOR MATCHED CURRENT DENSITY CHAMBERS

Date	Site	E-field-Measurement	Calculated Culture				
			Electrode Open-circuit Voltage $E_{oc}$ (mV)	Culture Cell Voltage $V_{cl}$ (mV)	Resistor Voltage $V_R$ (500 K) (mV)	Current Density $J_{cl}$ (mA/m <sup>2</sup> )	E-field (mV/m)
6/4/85	G-3	660	830	.89	815	1.81	5.74
	A-3	227	188	.3	187	.415	1.9
7/2/85	G-3	540	—	.20	100	.22	1.29
	A-3	200	160	.3	160	.356	1.94
7/9/85	G-3	630	204	.97	100	.22	6.25
	A-3	187	156	.6	144	.32	3.87
7/16/85	G-3	740	860	.87	830	1.84	5.61
	A-3	156	160	.4	164	.36	2.58
7/23/85	G-3	539	104	.835	170	.378	5.38
	A-3	160	169	.4	167	.37	2.58
7/30/85	A-3	196	170	.6	169	.376	3.87
8/6/85	G-3	650	208	.101	124	.276	.65
	A-3	230	175	.15	173	.38	.97
10/12/85	G-3	—	—	1.04	740	1.64	6.70
	A-3	—	191	.12	189	.42	.77

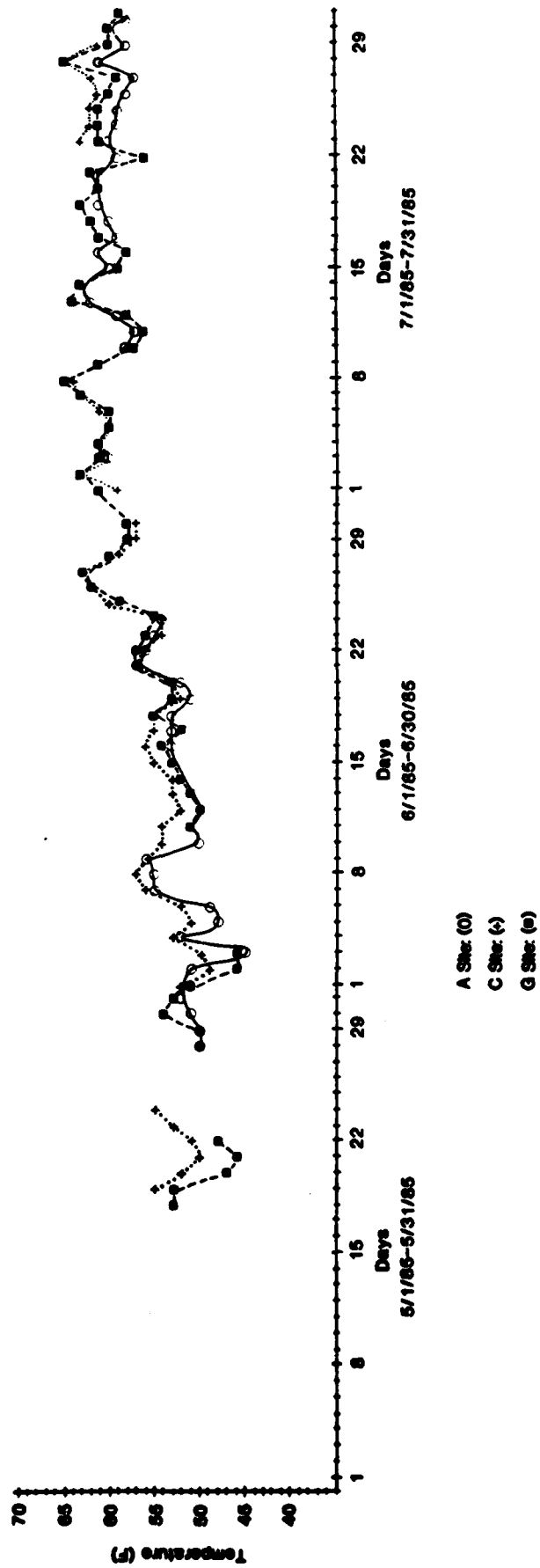
# 1985, MEASUREMENTS FOR MATCHED E-FIELD EXPOSURE CHAMBERS

Date	Site	Earth Electric Field E (mV/m)	Electrode Open-circuit Voltage Voc (mV)		Culture Cell Voltage V <sub>cl</sub> (mV)		Current-sense Resistor Voltage V <sub>R</sub> (100) (mV)		Calculated Culture Cell		
			1	2	1	2	1	2	Current Density MA/m <sup>2</sup>	E (mV/m)	
7/2/85	G	540	—	—	203	70	10	4	G <sub>1</sub> 111 G <sub>2</sub> 44	130 45	
	A	200	470	460	40.0	400	4.7	1.9	A <sub>1</sub> 52 A <sub>2</sub> 21	251 258	
7/9/85	G	630	2040	1680	97	97	10	16	G <sub>1</sub> 111 G <sub>2</sub> 177	625 625	
	A	187	267	450	28.9	28.9	4.8	4.6	A <sub>1</sub> 53 A <sub>2</sub> 51	186 186	
7/16/85	G	740	2100	1740	115	90	20	16	G <sub>1</sub> 222 G <sub>2</sub> 177	741 580	
	A	156	470	460	24.0	17.0	3.5	2.3	A <sub>1</sub> 38.9 A <sub>2</sub> 25.6	155 110	
7/23/85	G	540	1040	1776	835	835	17	14	G <sub>1</sub> 188 G <sub>2</sub> 155	538 538	
	A	160	470	460	20.0	14.0	2.8	2	A <sub>1</sub> 31 A <sub>2</sub> 22	129 90	
7/30/85	A	196	465	470	30	15	5.0	5	A <sub>1</sub> 55.6 A <sub>2</sub> 55.6	194 968	
8/6/85	G	650	2080	1765	101	84	20.8	9.9	G <sub>1</sub> 232 G <sub>2</sub> 110	651 542	
	A	230	470	480	35.6	31.0	4.0	5	A <sub>1</sub> 44 A <sub>2</sub> 55	230 200	
10/12/85	G	—	1960	1700	—	98	—	7	G <sub>1</sub> 220 G <sub>2</sub> 18	— 632	
	A		460	490	41	6	2.0	3.0	A <sub>1</sub> 22 A <sub>2</sub> 33	264 316	

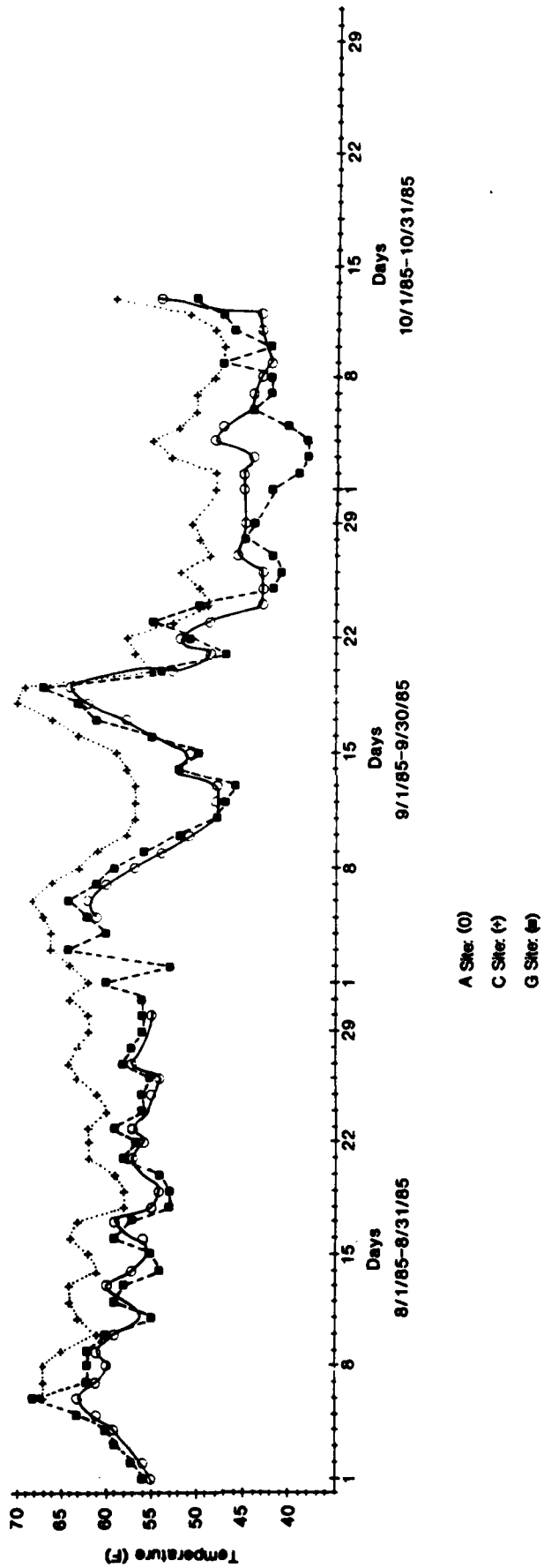
## **APPENDIX II**

### **Daily Record of Temperature at Field Sites**

Temperature Graphs 5/1/85-7/31/85



Temperature Graphs 8/1/85-10/31/85





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